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THE EVOLUTION OF THE ADAM V/STOL CONCEPT

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FOREWORD

The ADAM turbofan V/STOL concept has grown through an evolutionary process extending over the past ten years. The current formulation of the concept is perhaps best understood by reviewing its evolutionary growth. Work on the concept was initiated by establishing the concept philosophy as set forth in Appendix A. The various relevant tests which have served to guide the evolution of the concept are listed in outline form in Appendices B and C. The various design studies which have definitized the successive stages of concept growth are listed in Appendix D.

In order to clarify the description of the evolutionary process, the treatment herein has been subdivided under the following headings:

A. Basic Configuration
B. Propulsive Wing Section
C. Fan Inlet Configuration
D. Tail Configuration
E. Hover Control
F. Hover Pitch Control System
G. Hover Roll Control System
H. Hover Yaw Control System
I. Gas Generator Location and Inlet Configuration
J. Hot Gas Ducting System
K. Landing Gear

Many individuals in the contractor's organization, in the Military Services, and in the NASA Langley and Ames Research Centers have worked long and hard in bringing the ADAM concept to its current degree of refinement. Changes and improvements are still being made at a steady rate, and continuing growth and improvement may be expected in the future. A review of the history of this evolution also reveals that the earlier philosophy provided a guidance which is largely valid to this day.

A. BASIC CONFIGURATIONS

Some of the more significant basic configurations are shown in chronological order in Figures A.1 through A.13, inclusive.

Figures A.1 through A.3,inclusive, depict evolution of the tail configuration based upon low speed wind tunnel testing (Appendix B.1).

Figures A.4 through A.6 illustrate early ADAM II designs. Starting with Figure A.7, the far-reaching effects of incorporating a nose fan for hover pitch control become apparent.

Figure A.8 reflects some of the changes resulting from adopting gas generators of the GE1/J1--STF240--GMA100 state-of-the-art rather than the earlier J85--J52--J60 state-of-the-art.

Figure A.9 illustrates a change-over to a forward-facing nose fan based upon the findings of the ARO-Durham semi-span model test (Appendix A.5). Figure A.10 shows the tail configuration changes indicated by wind tunnel tests of the Hi/Lo Model (Appendix A.6).

Figure A.11 shows a version designed for the close support mission. Six wing fans were used to increase bypass ratio and wing span for missions attaching importance to good STOL performance and prolonged hover time.

Figure A.12 shows a further development of the close support design study. The six wing fan approach was abandoned as too complex for a small tactical airplane. Various other changes were made to incorporate findings of recent test programs and to enhance survivability in a close support environment. The step change nature of the modifications in this version led to redesignation of the concept to "ADAM III".

Figure A.13 shows a modification of the Figure A.12 configuration involving an interchange of the front fan and pilot locations.

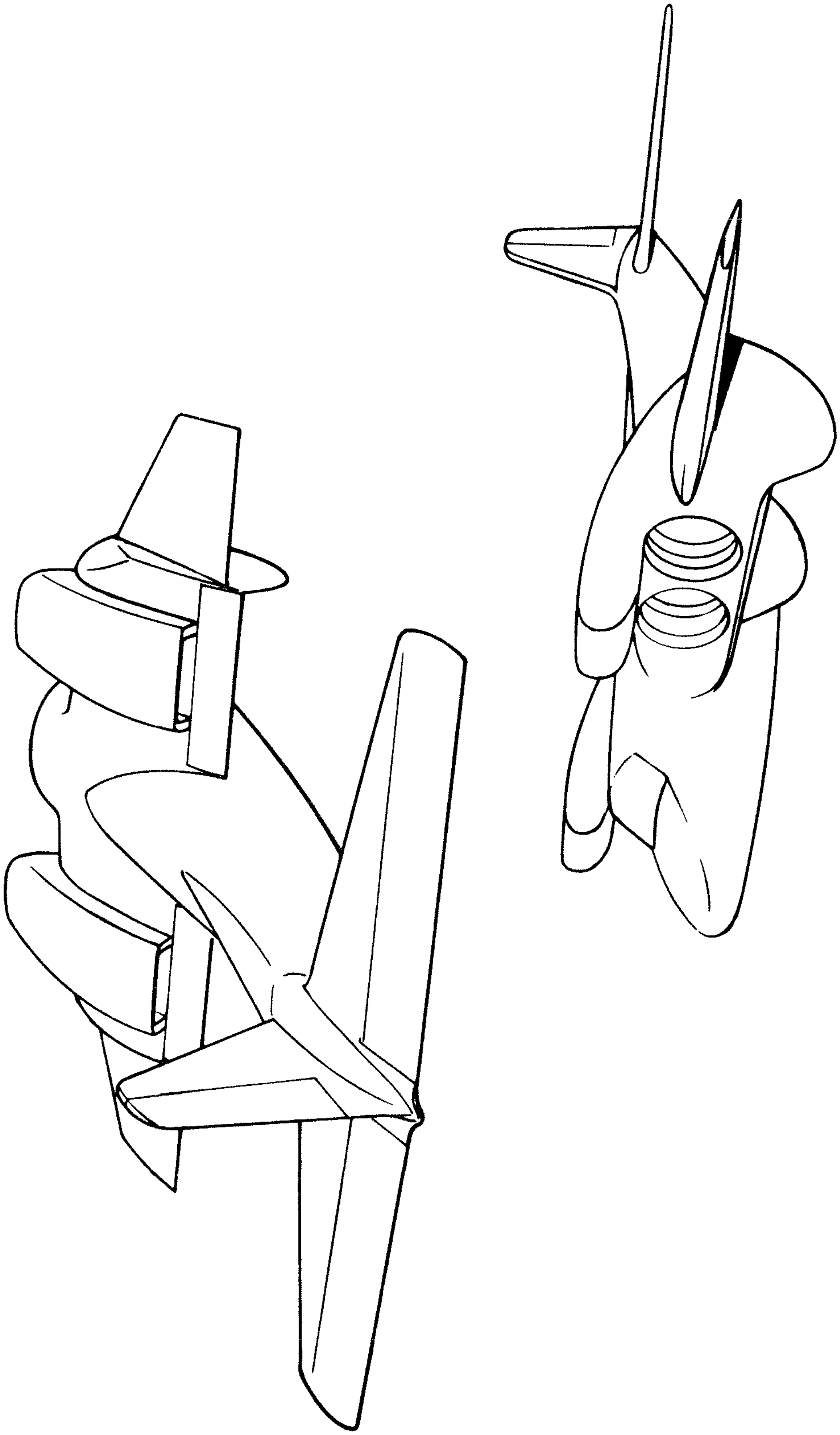

Figure A.1 Basic Configuration ADAM I Concept July 1959

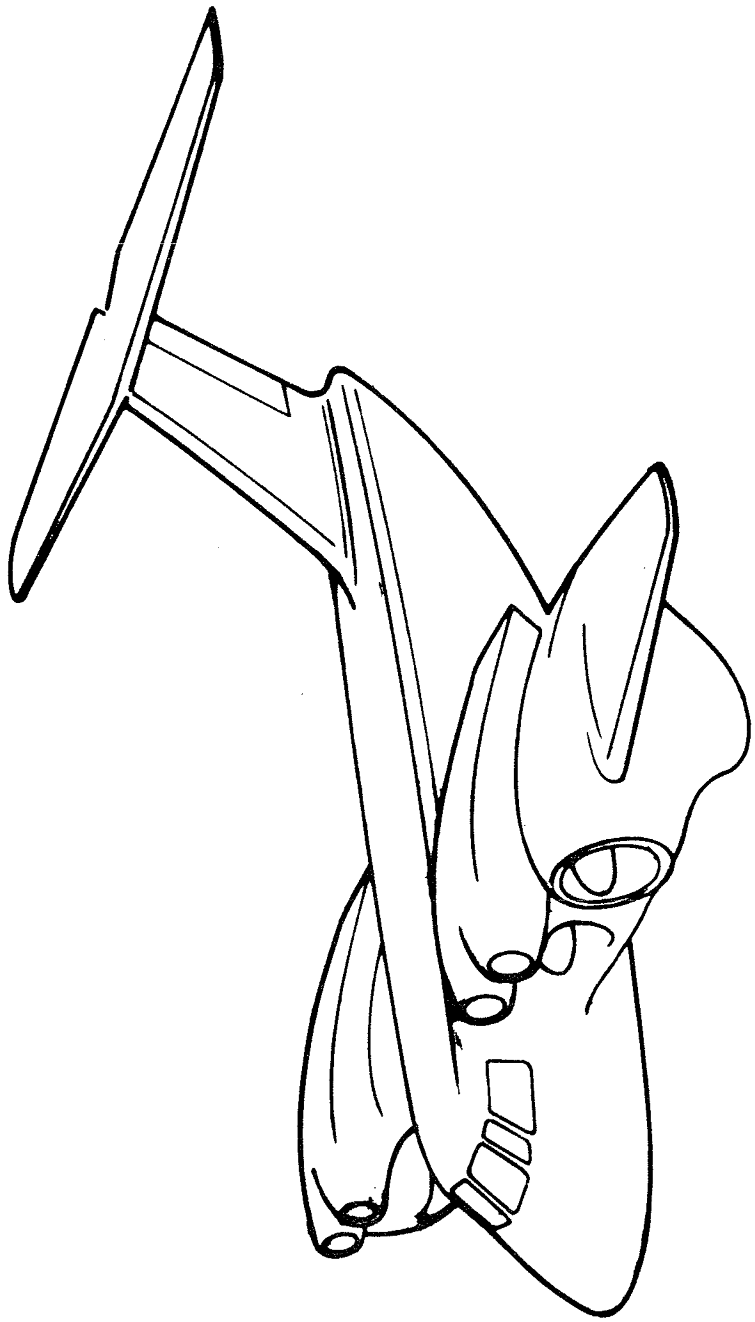

Figure A.2 Basic Configuration ADAM I Concept October 1959

Figure A.3 Basic Configuration ADAM I Concept January 1960

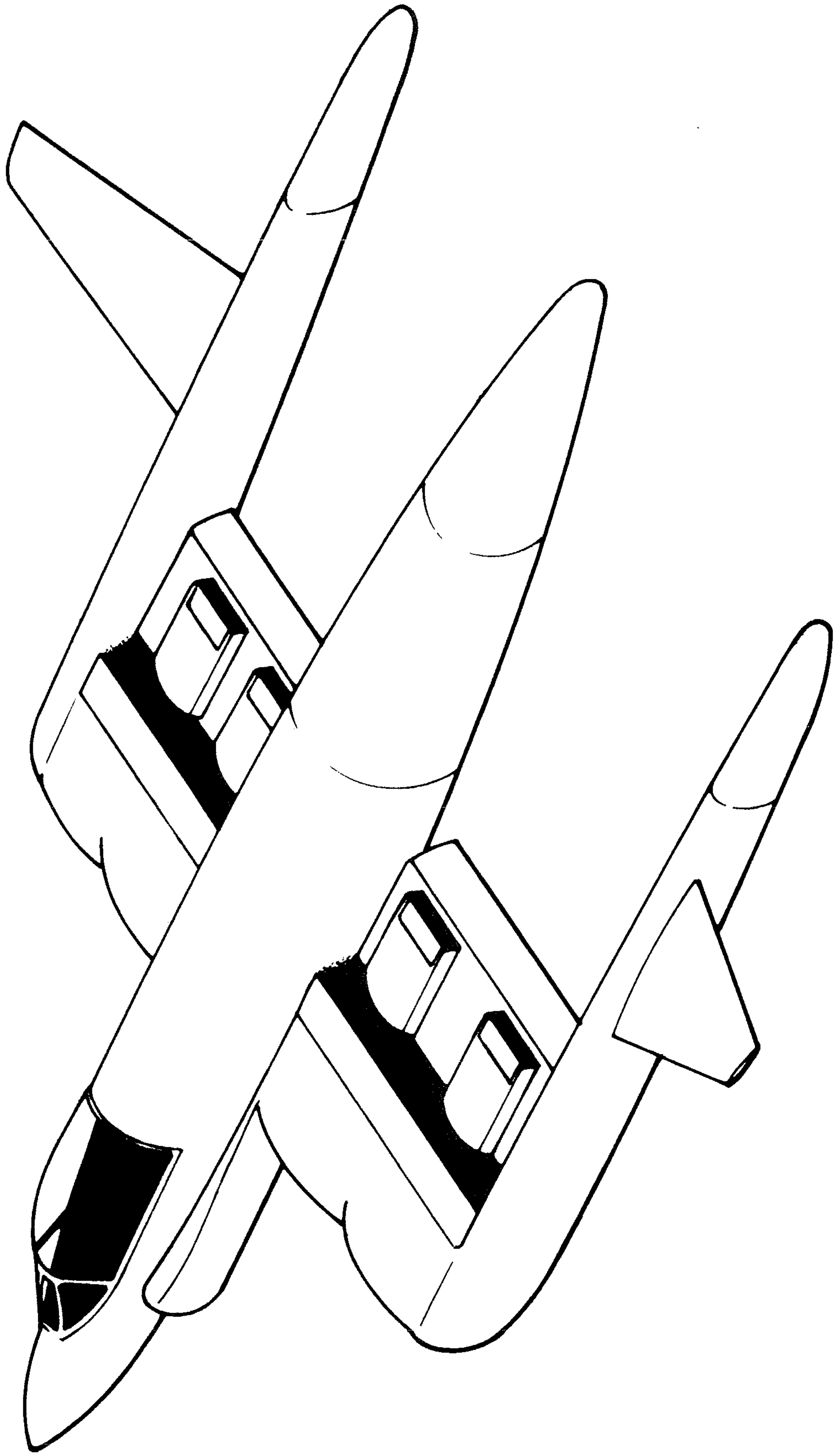

Figure A.4 Basic Configuration ADAM I Concept April 1962

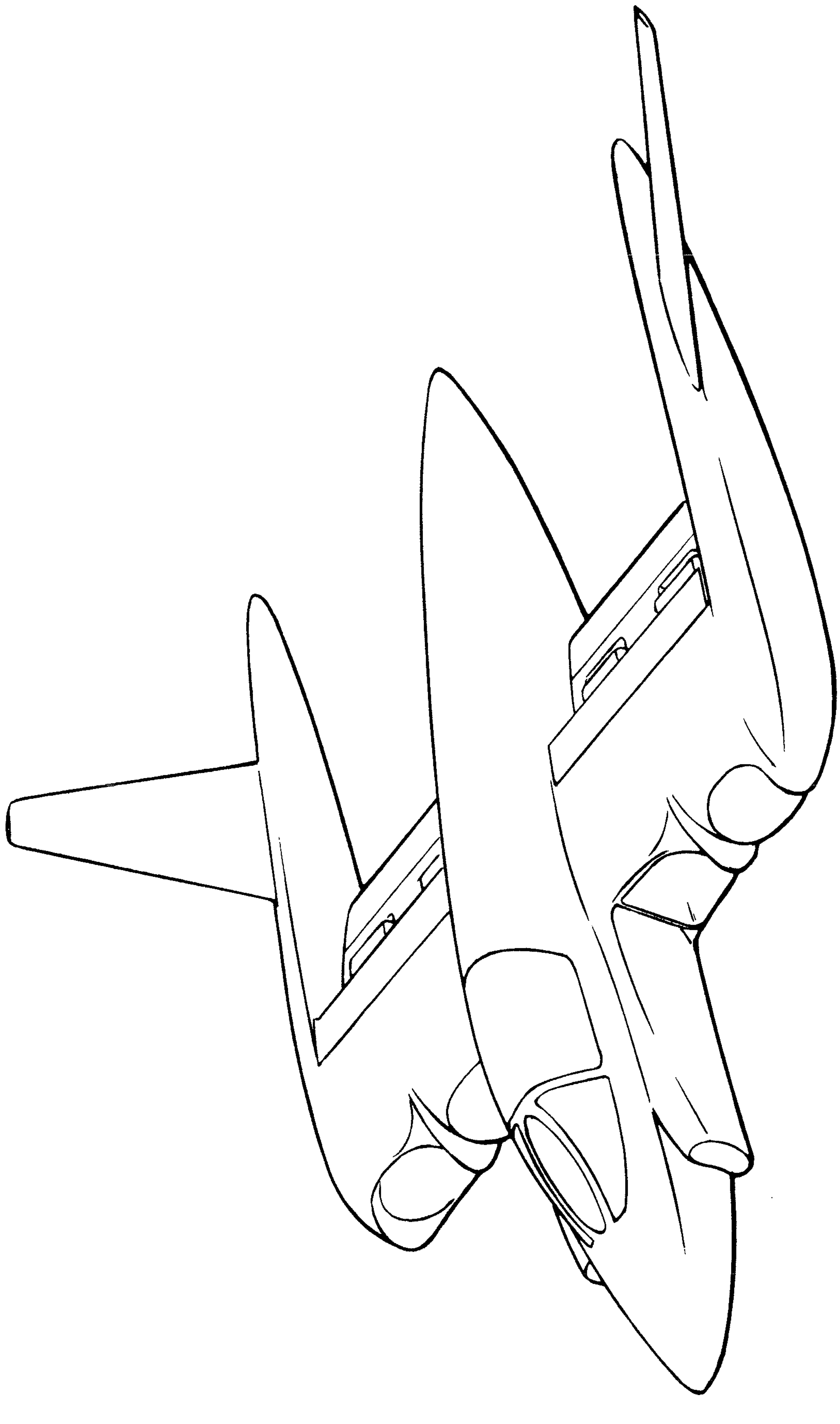

Figure A.5 Basic Configuration ADAM I Concept June 1962

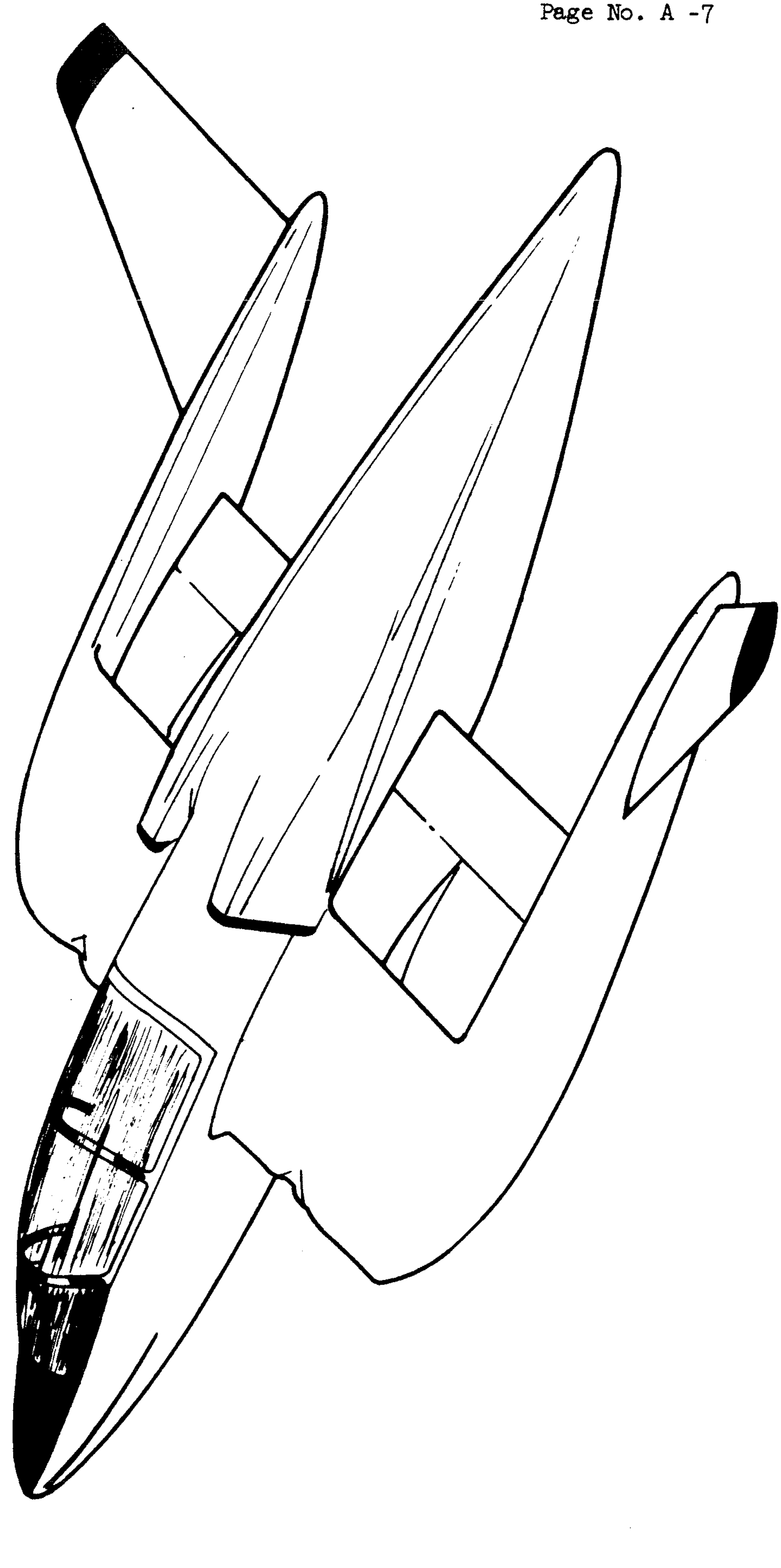

Figure A.6 Basic Configuration ADAM I Concept November 1962

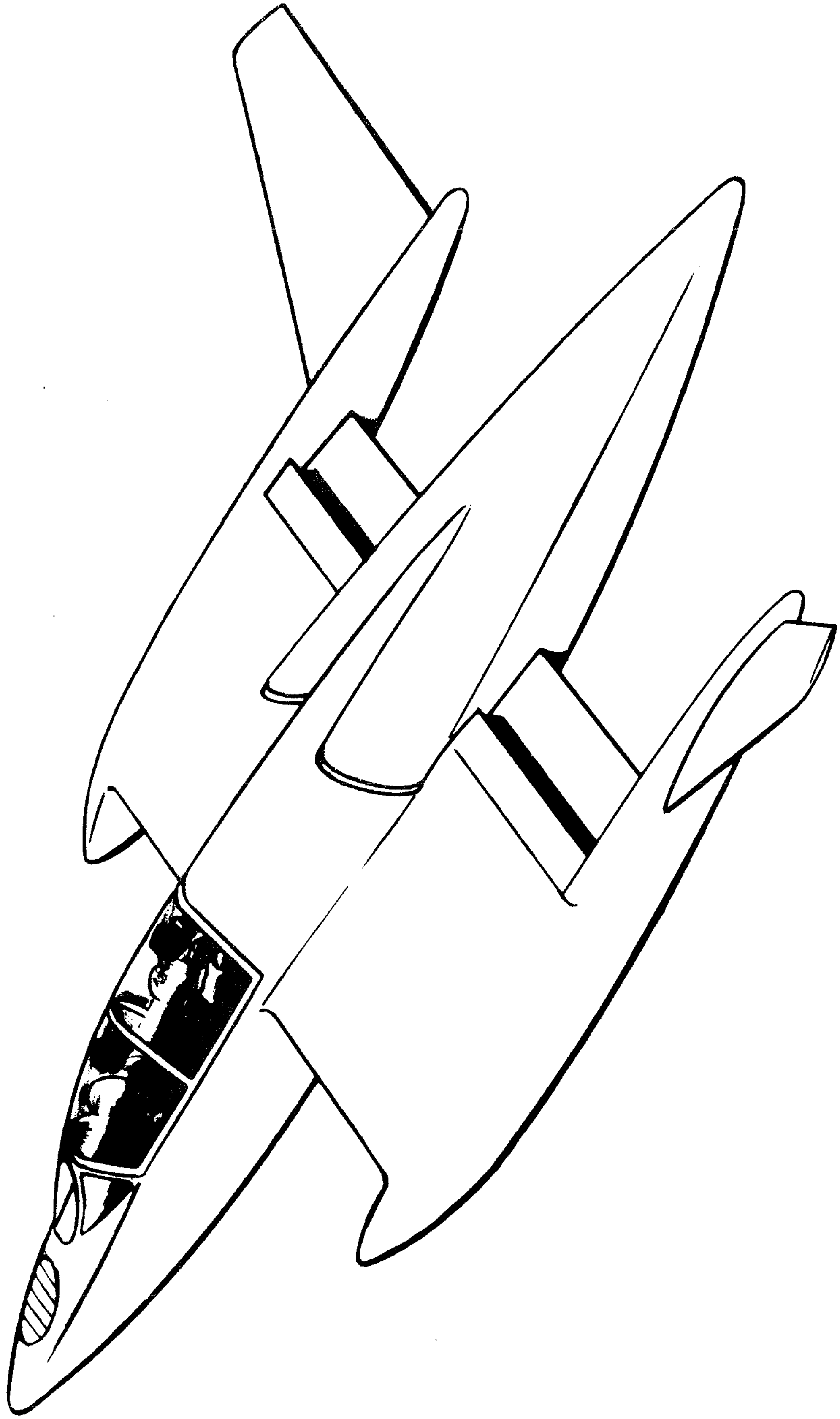

Figure A.7 Basic Configuration ADAM I Concept January 1964

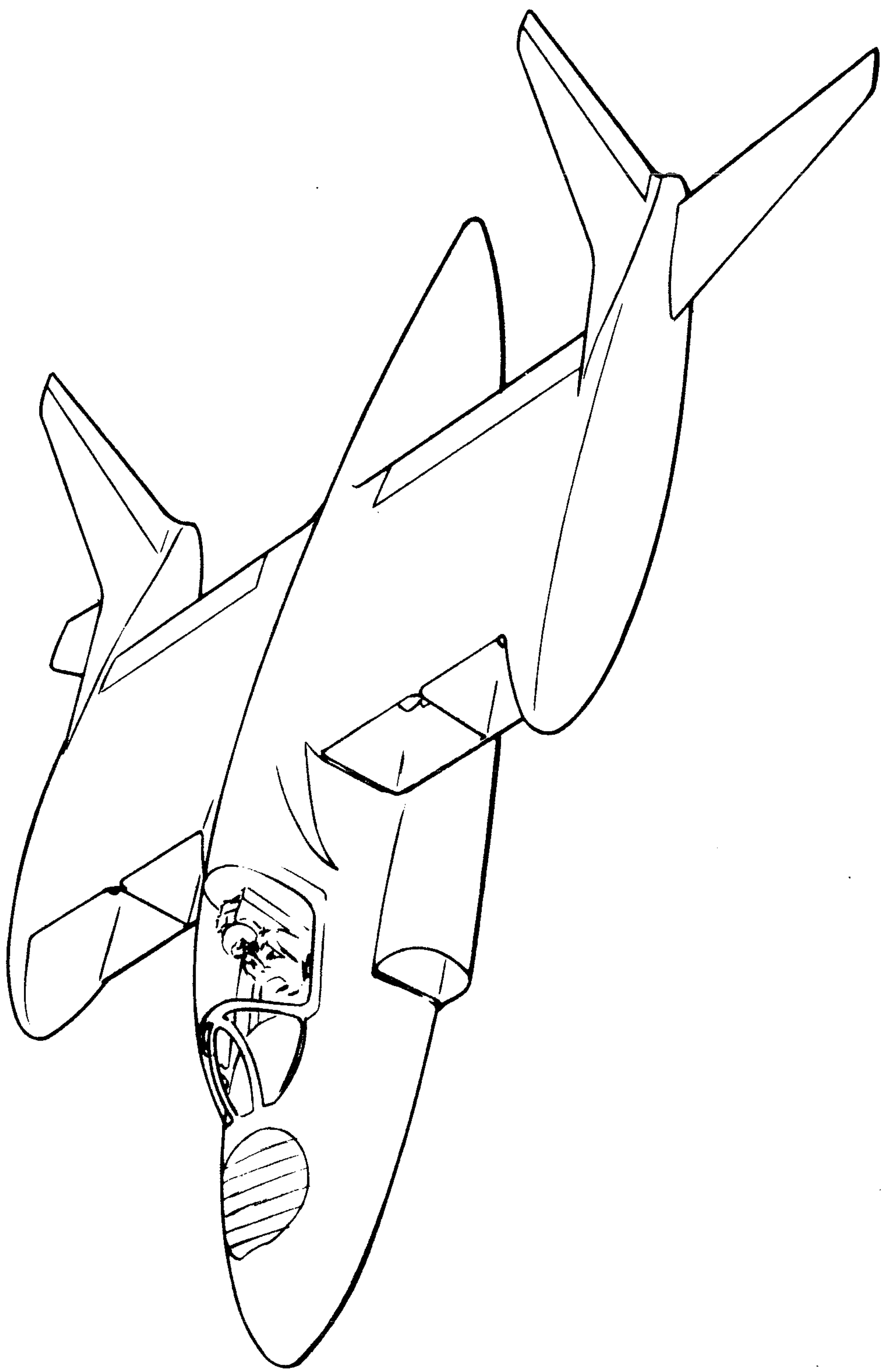

Figure A.8 Basic Configuration ADAM I Concept May 1964

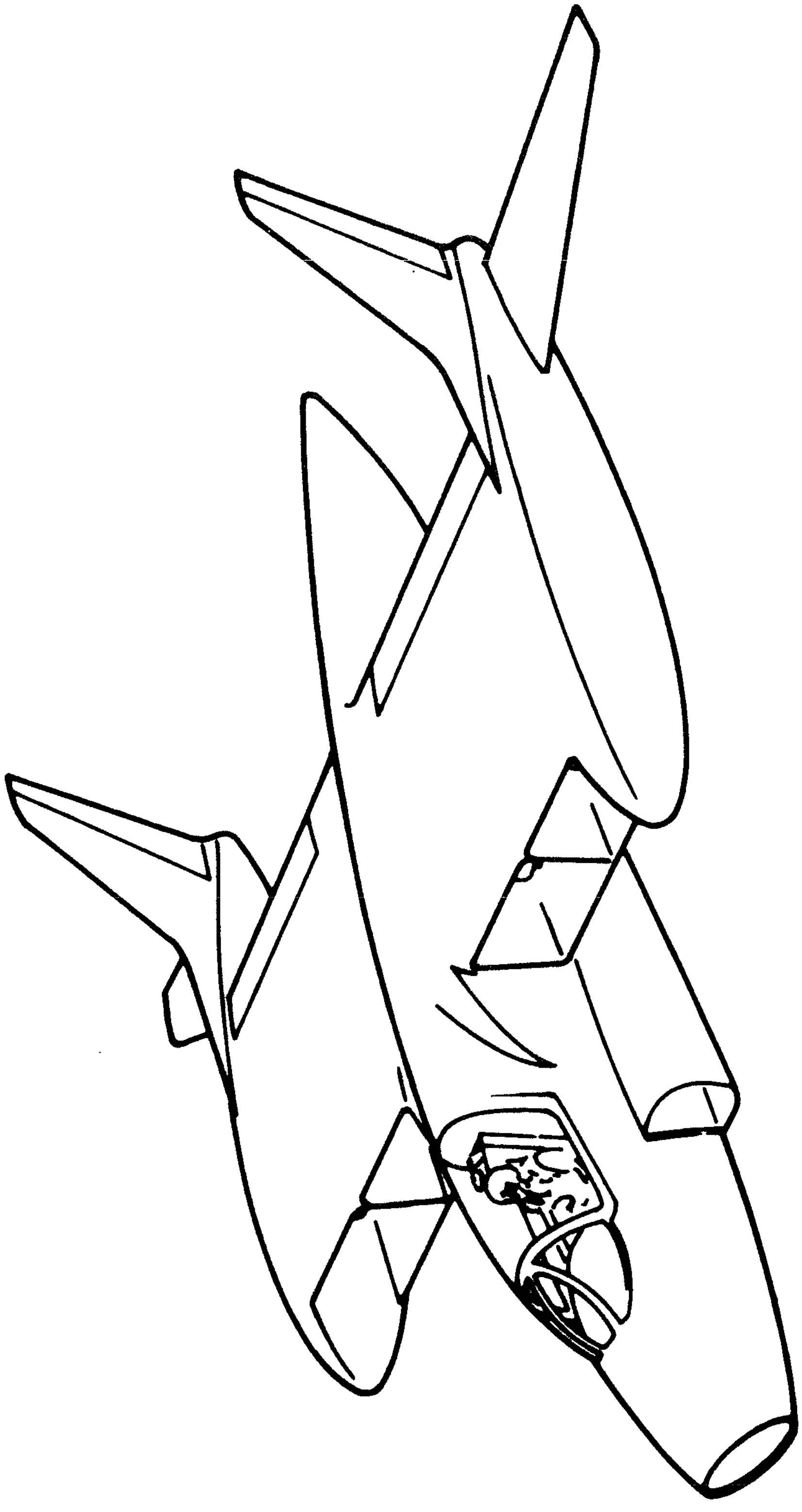

Figure A.9 Basic Configuration ADAM I Concept September 1965

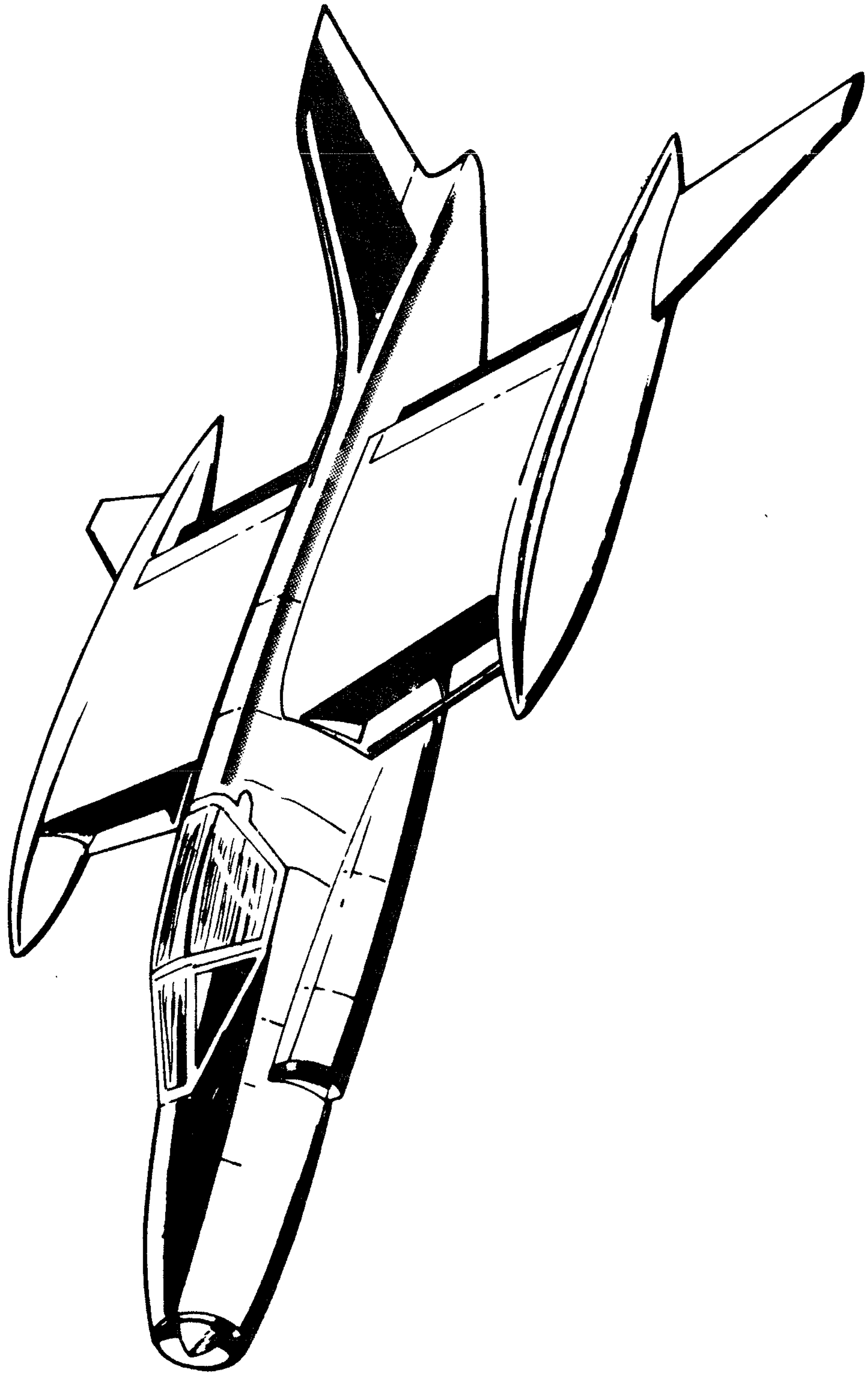

Figure A.10 Basic Configuration ADAM II Concept February 1967

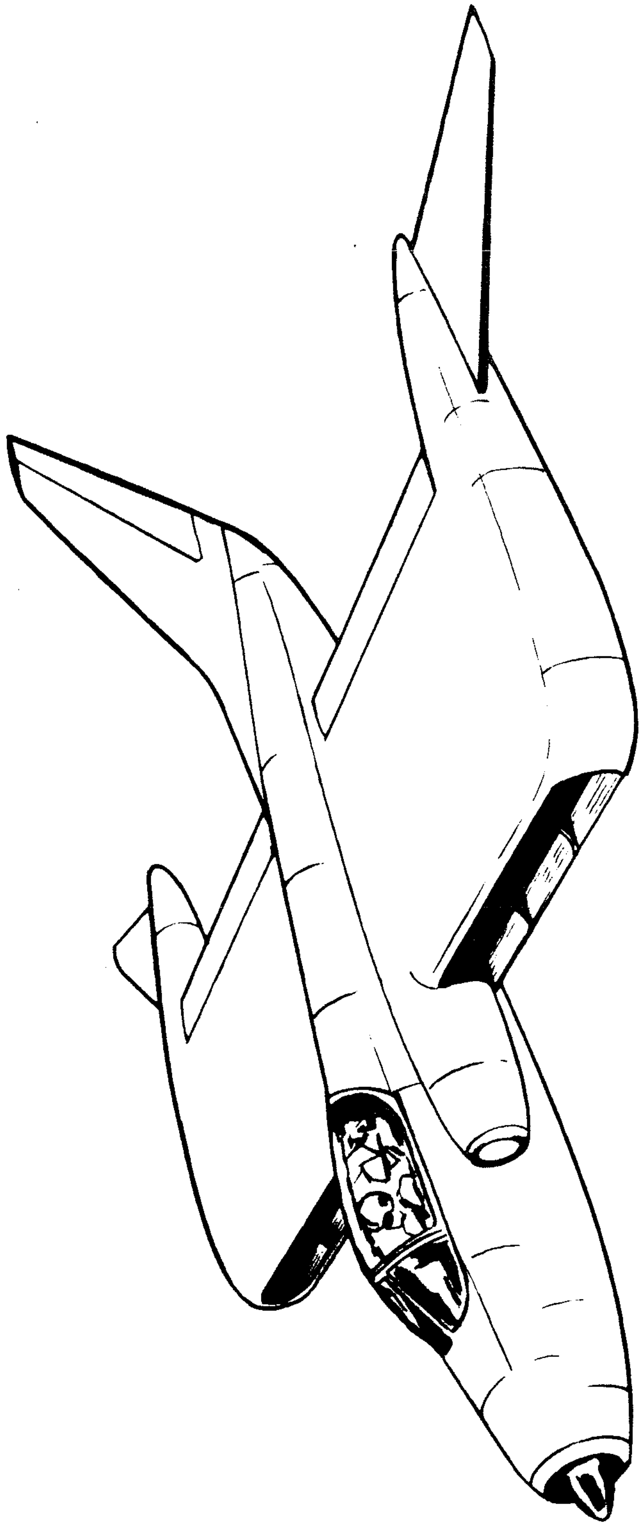

Figure A.11 Basic Configuration ADAM II Concept December 1967

Figure A.12 Basic Configuration ADAM III Concept May 1968

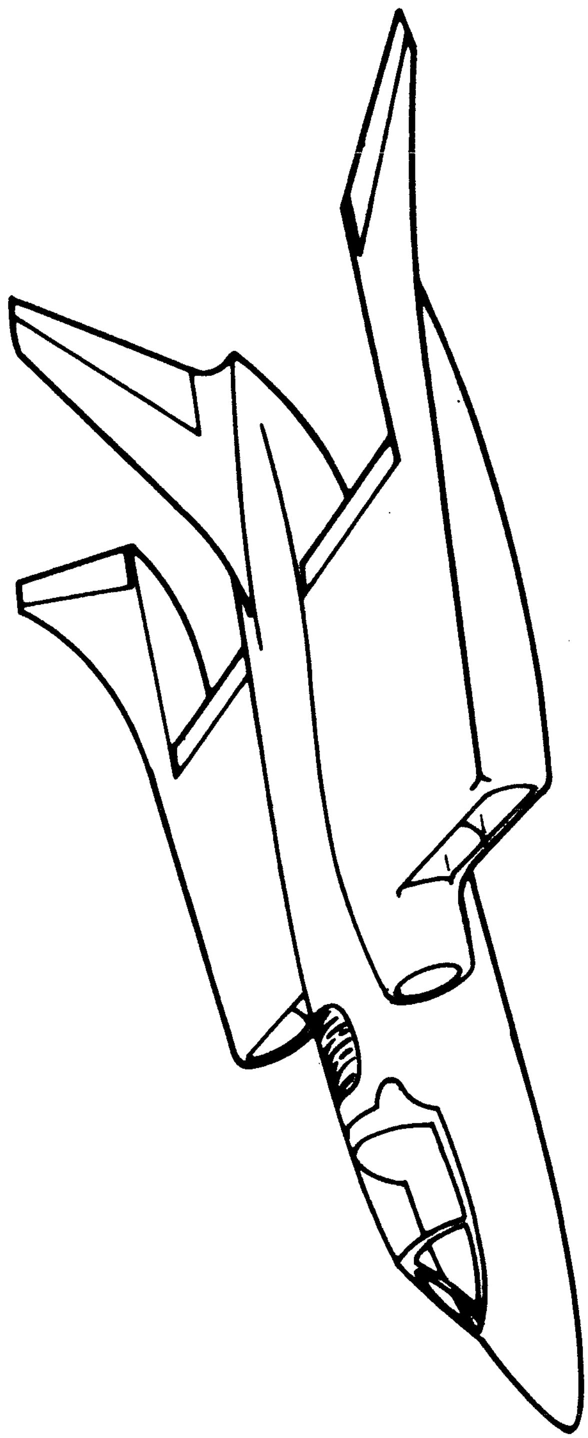

Figure A.13 Basic Configuration ADAM III Concept June 1968

B. PROPULSIVE WING SECTION

The original ADAM concept envisioned using a "propulsive pod" comprising two forward-facing fans shaft-driven by power turbines as shown in Figure B.1. Two gas generators were mounted in a nacelle above the fans. One or more propulsive pods were mounted on each side of the fuselage. The external surfaces of the pods comprised the aerodynamic lifting surface or wing of the airplane. The fan flow was vectored by movement of multiple-jointed doors or flaps which comprised major portions of the upper and lower walls of the fan ducts. The two fan ducts coalesced into a single duct immediately downstream of the fans. This increased duct aspect ratio in the vectoring bend and tended to reduce flow losses. It would, however, have made one-fan-out operation infeasible. Further particulars of this configuration are described under other headings below.

The initial low speed wind tunnel test (Appendix B.1) showed that the upper surface of the wing had too much curvature. One consequence was that substantial portions of the wing surface became stalled at angles of attack as low as 6°. The juncture between the engine nacelles and the wing aggrevated the stalling tendency. Very extensive filleting of this juncture alleviated but did not eliminate the difficulty.

In the hover mode, the center of gravity of the airplane must be on or very near the resultant hover thrust vector. The center of gravity location in flight is closely the same as in the hover mode. The horizontal tail size needed for any given static margin increases with the distance between the center of gravity and the aerodynamic center of the wing. The aerodynamic center of a propulsive wing-fuselage combination was found to be unusually far forward. Therefore, every effort was made to keep the hover thrust vector as close to the fan as practicable. Nevertheless, the center of gravity location, as dictated by hover thrust vector location, remained undesirably far aft, so that all ADAM I and early ADAM II configurations needed large horizontal tails.

The initial propulsive duct test (Appendix B.2) showed gratifyingly low flow losses in the twin-fan inlet, duct, and vectoring bend. This test also indicated that turbulence such as that generated by a fan (windmilling rotors were used in this particular model) substantially reduced the flow losses, apparently by energizing the boundary layers on the walls of the fan duct, thereby suppressing tendencies toward flow separation. A subsequent test of a powered, twin-fan propulsive pod, never reported, demonstrated excellent performance of the fan inlet (high inlet recovery). Centrifugal force acting on the curvilinear flow in the vectoring bend, however, set up a strong static pressure versus velocity distortion. This distortion was transmitted upstream through the subsonic flow field. The distortion level at the station of the close-coupled fan was far beyond tolerable limits.

The next wing section, shown in Figure B.2, was introduced as part of an ADAM II concept. It called for the gas generators to be located in the fuselage, departing from the pure propulsive pod approach. This change eliminated the source of flow disturbances on the upper surfaces of the wings. Thick trailing edge flaps were used, moderating the curvature of the upper surface of the wing. The hot gas ducting and power turbines were mounted in an island, with both fan and turbine flows passing both over and under the island. Fan flows were discharged over the entire span of the flaps, but turbine flow nozzles occupied only the zones immediately behind the turbines.

A high speed wind tunnel test (Appendix B.4), of a model reasonably representative of this wing section, showed that the Mach Number for drag divergence was approximately 0.9, which was far higher than predicted.

In order to overcome the fan duct flow distortion problem, the concept called for vectoring the flow with a three stage cascade. The second and third stages were made variable. It was considered necessary to use thirteen vanes in each stage of this cascade. As in the ADAM I configuration, it was necessary to keep the vectoring device as close to the fan as practicable.

A forward wing beam was located near the fans and a rear wing beam was located behind the power turbines. Wing torsion was carried as differential bending of these two beams.

Further study indicated that it would be preferable to exhaust the turbine flow all either over or under the trailing edge flap. The underside was first selected to facilitate thrust vectoring. The resultant wing section is shown in Figure B.3.

With the introduction of a nose fan into the concept, as discussed below under the heading "Hover Pitch Control System", a strong lift thrust became available in the front end of the airplane during the hover mode. This made it possible to move the hover thrust vector of the wing fans further aft without acquiring a rearward Center of Gravity location. ADAM concept airplanes no longer had to be fitted with oversized horizontal tails. More room became available for the thrust vectoring process, making it possible to reduce the nubmer of cascade vanes as shown in Figure B.4.

The change-over to nose fan pitch control also made space available in the front half of the propulsive wing for a truss-type wing beam and torque box. Upper and lower members of this structure are of conventional skin and stiffener design. The vertical members are trusses with streamlined stays extending across the fan ducts at locations where the airflow velocities are relatively low. This structural design change was important because by this time analyses had shown that the differential bending approach previously used was unattractive for outboard tail airplanes.

The change-over to nose fan pitch control also served to remove all primary structure from close proximity to hot gas components. With the protection afforded by a light, insulated firewall, the structural integrity of the wing could be preserved even though major damage had been incurred by the hot gas ducting.

In this version of the propulsive wing section, all hot gas was exhausted over the upper surface of the flaps, using the full span of the flap, and all cold fan flow under the lower surface. A retractable vane was relied upon to assist in vectoring the hot gas flow downward in the hover mode. The fan exhaust nozzle was basically two-dimensional, but additional nozzle area had to be obtained by using some of the space on either side of each power turbine. The appearance was that of a rectangular duct with bulged fairings under each turbine. The rearward part of this fairing had to be made movable in order to permit deflection of the trailing edge flap. The flows from adjacent fans were separated by partitions all the way to the jet nozzles, making one-fan-out operation feasible.

With some further study, it was found possible to reduce the total number of cascade vanes from the eleven shown in Figure B.4 to eight. This version, the first fully acceptable wing section design achieved, became possible only after the nose fan was incorporated as the means for providing pitch trim and control in the hover mode.

The variable cascade approach shown in Figure B.4 could undoubtedly have been made to work with acceptably low flow losses and upstream distortion indices. The design, however, left much to be desired as regards the mechanical complexity of the variable cascades. Some flow losses were of course inevitable with high velocity air flowing over multiple vanes.

A break through was achieved with the concept shown in Figure B.5. It was reasoned that it should be possible to bulge the lower surface of the fan duct so as to set up a distorting effect which would be equal and opposite to the distortion produced by centrifugal force upon the curvilinear flow in the vectoring bend. This would make it possible to return to the low loss, open-duct vectoring approach of the original ADAM I concept without incurring the unacceptable flow distortion at the station of the fan. The problem of deriving a suitable theoretical treatment was massive. This obstacle was eventually overcome as follows. A two-dimensional potential flow computer program modified for compressibility effects was generated to define a two-dimensional duct shape for 90 degrees of turning with a bulged inner wall. The program utilizes the Swartz-Christoffel transformation to ascertain particulars of the potential flow, and the Karman-Tsien compressibility factor to correct for compressibility effects. The program includes provision for calculating the boundary layer shape factor, serving to locate areas of incipient separation. In addition, it determines the thickness of the displacement boundary layer at all locations of interest, showing how the walls of a physical fan duct must be displaced from the locations of the theoretical streamlines. The desired configuration is arrived at by cut and try variation of the coefficients which define the rectolinear boundaries to which the Swartz-Christoffel transformation is applied. It was found possible to arrive at contours which, on this theoretical basis, provided acceptably small flow distortions at the station of the fan.

The above theoretical geometry was then applied to a two-dimensional model which was tested in the LTV free surface water table facility. The correlation of water table data with the theoretical prediction was highly satisfactory.

The contoured vectoring bend geometry was then applied to a three dimensional model and tested downstream of a representative fan in a test program sponsored by the Army (Appendix C.1). The test results compared very well with the earlier test and theoretical results. The new contouring was applied to all subsequent wing section designs.

Tests of the Hi/Lo model at NASA Langley (Appendix B.6.C) suggested that the rather sharp-edged fan inlets of the model were causing serious aerodynamic disturbances, particularly at higher angles of attack and under high spillage conditions. Subsequent developmental static testing of a twin fan inlet (Appendix B.7) under Army Ames sponsorship yielded very gratifying results. Incidentally, the recovery performance of the early ADAM inlet, tested but not reported, fell precisely on the data curve for the new tests. An actual airplane would generally be flown with a few degrees angle of attack, and the approaching flow would generally have an upwash component. Therefore, it appeared logical to cant the fan inlets downward a few degrees. This seemed particularly desirable since the fan shaft axis was already inclined downward a few degrees for packaging reasons. This change was incorporated in subsequent wing sections.

A member of the NASA Langley team working on the Hi/Lo test program (Appendix B.6) pointed out that it would be possible to increase the front end radius of the trailing edge flap quite substantially by lowering the center of rotation down to the lower surface of the flap. Doing so should improve flow conditions over the upper surface of the flap. This should make it possible to keep the flow attached by Coanda effect, eliminating the need for auxiliary retractible vanes. A quick check during the ARO-Durham semi-span test (Appendix B.5) had indicated the desirability of increasing this radius.

High speed tests of the Hi/Lo Model at Langley (Appendix B.6) suggested that the lower surface of the flap had too much upsweep. This line was improved in all future wing section designs. This change also further increased the front end radius of the flap.

As time went on, the performance of available gas generators gradually increased (more gas horsepower per pound per second of hot gas flow). As the turbofan cycles were modified to capitalize on improved gas generator performance, the design fan pressure ratios increased step by step. This led to a reduction in the area needed for the fan jet nozzle. With careful design, it finally became possible to arrive at a fully two-dimensional fan jet nozzle, with no bulges under the power turbines.

The above evolution led to the wing section design shown in Figure B.5. This configuration is closely represented in the Army Semi-span Model being tested at Army Ames (Appendix C.2).

Further inprovements are anticipated particularly as regards the internal lines of the fan and turbine jet nozzles with related changes to adjacent external lines, and as regards the design of the trailing edge flap.

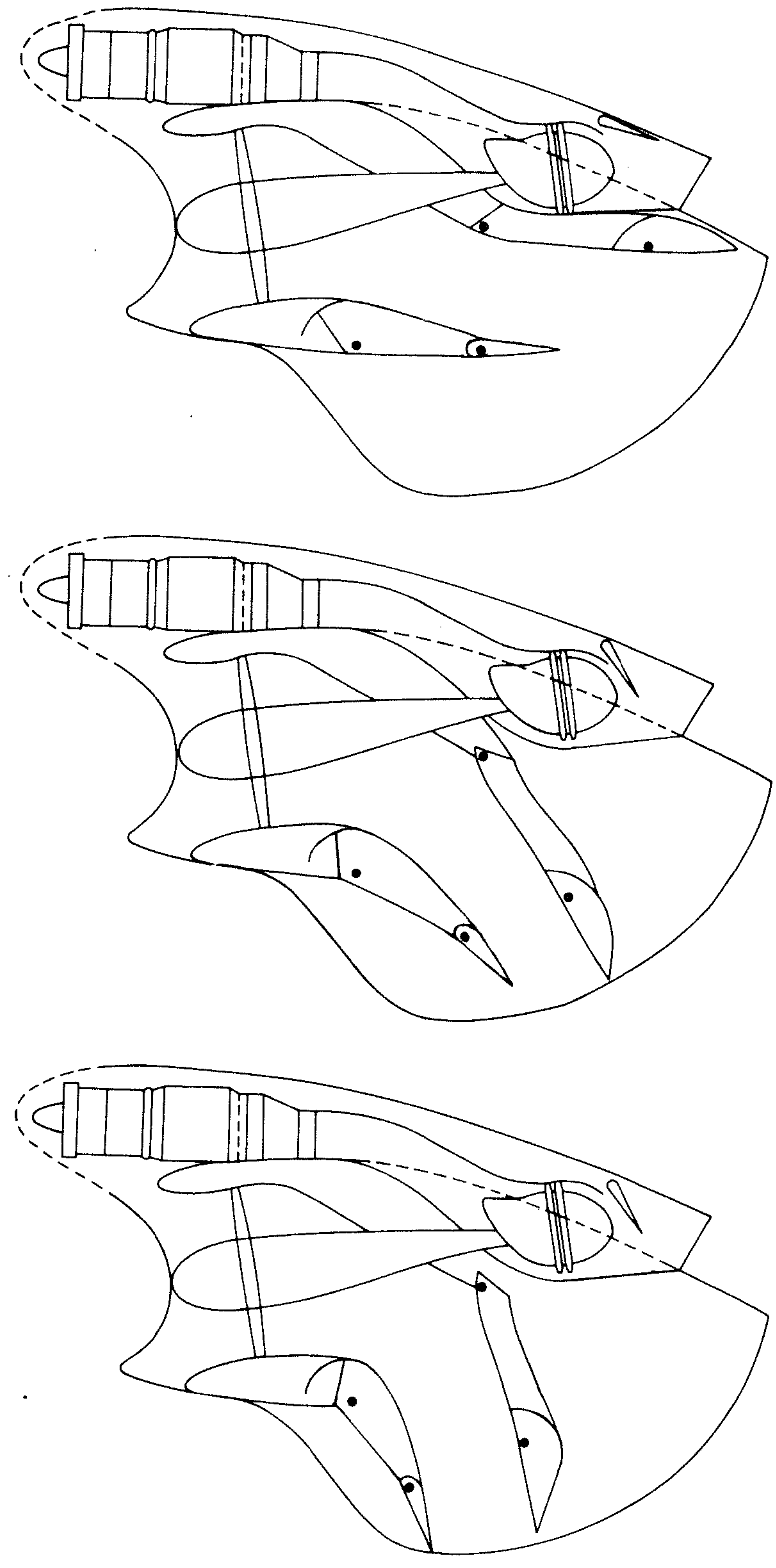

Figure B.1 Propulsive Wing Section All ADAM I Configurations

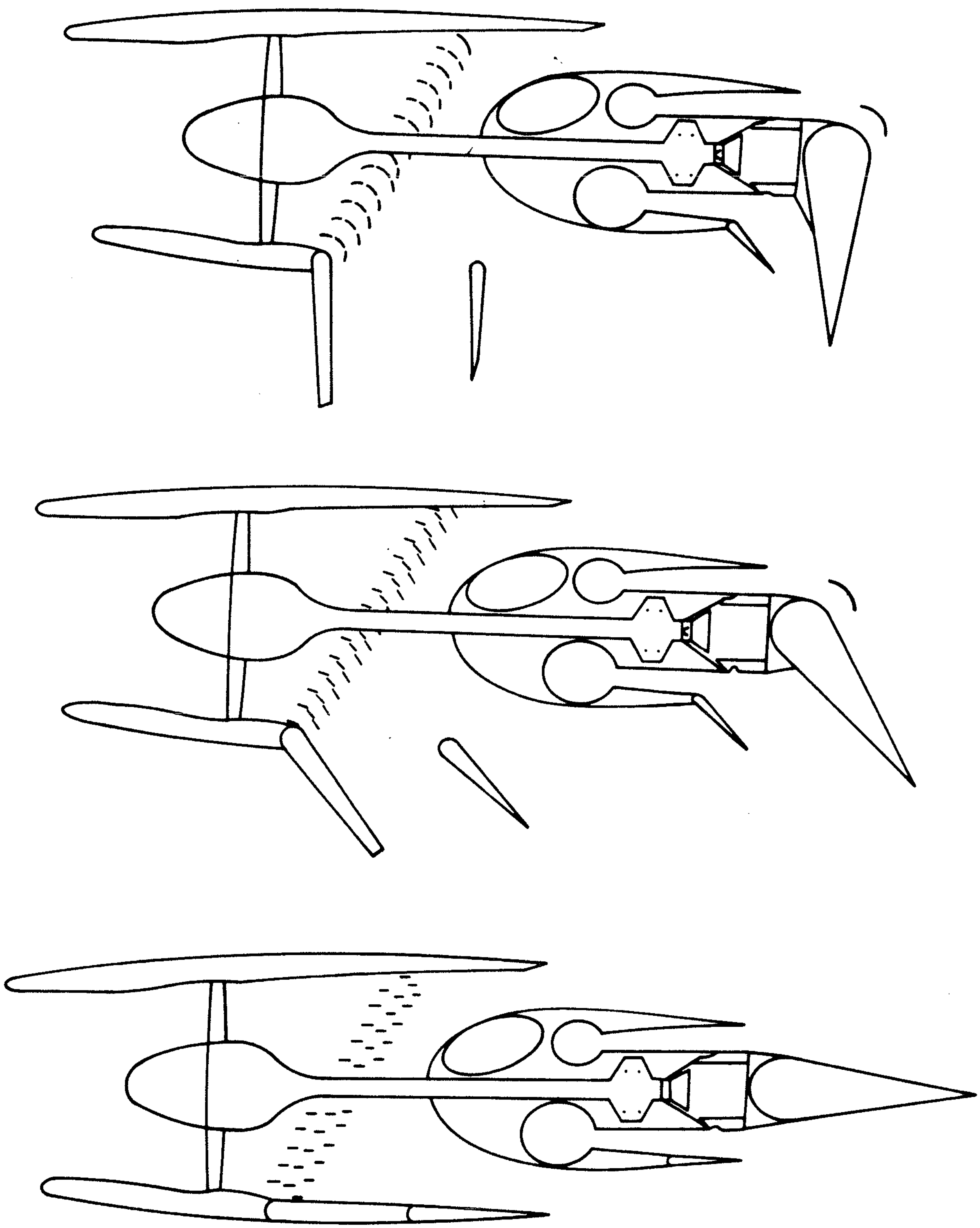

Figure B.2 Propulsive Wing Section Basic Configurations A.4 and A.5

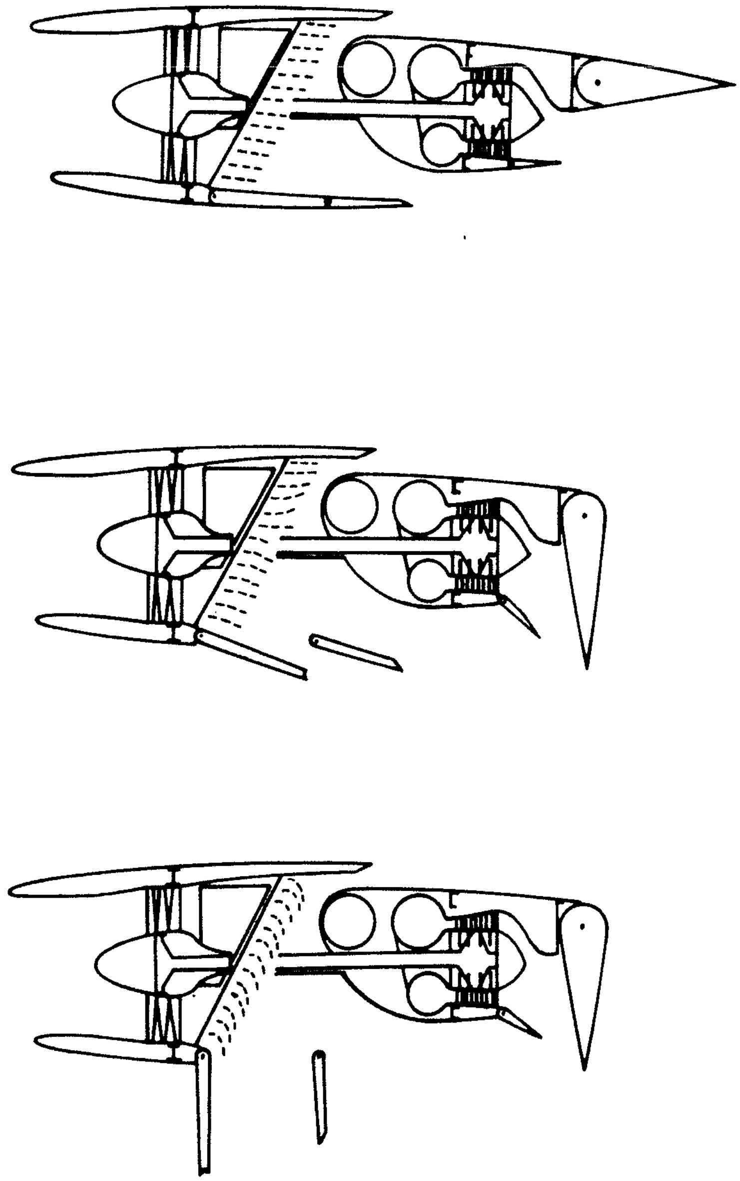

Figure B.3 Propulsive Wing Section Basic Configuration A.6

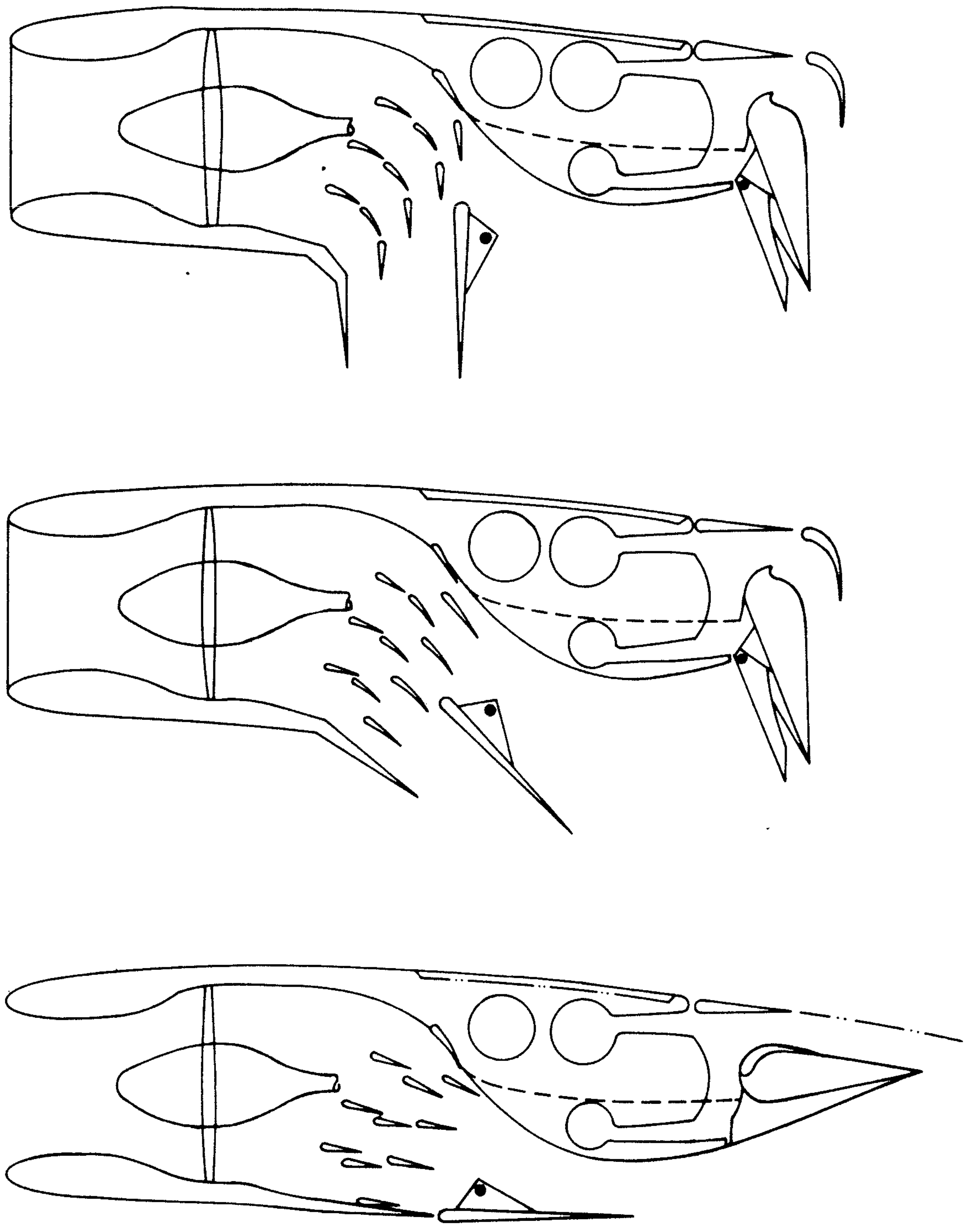

Figure B.4 Propulsive Wing Section Basic Configurations A.7, A.8, and A.9

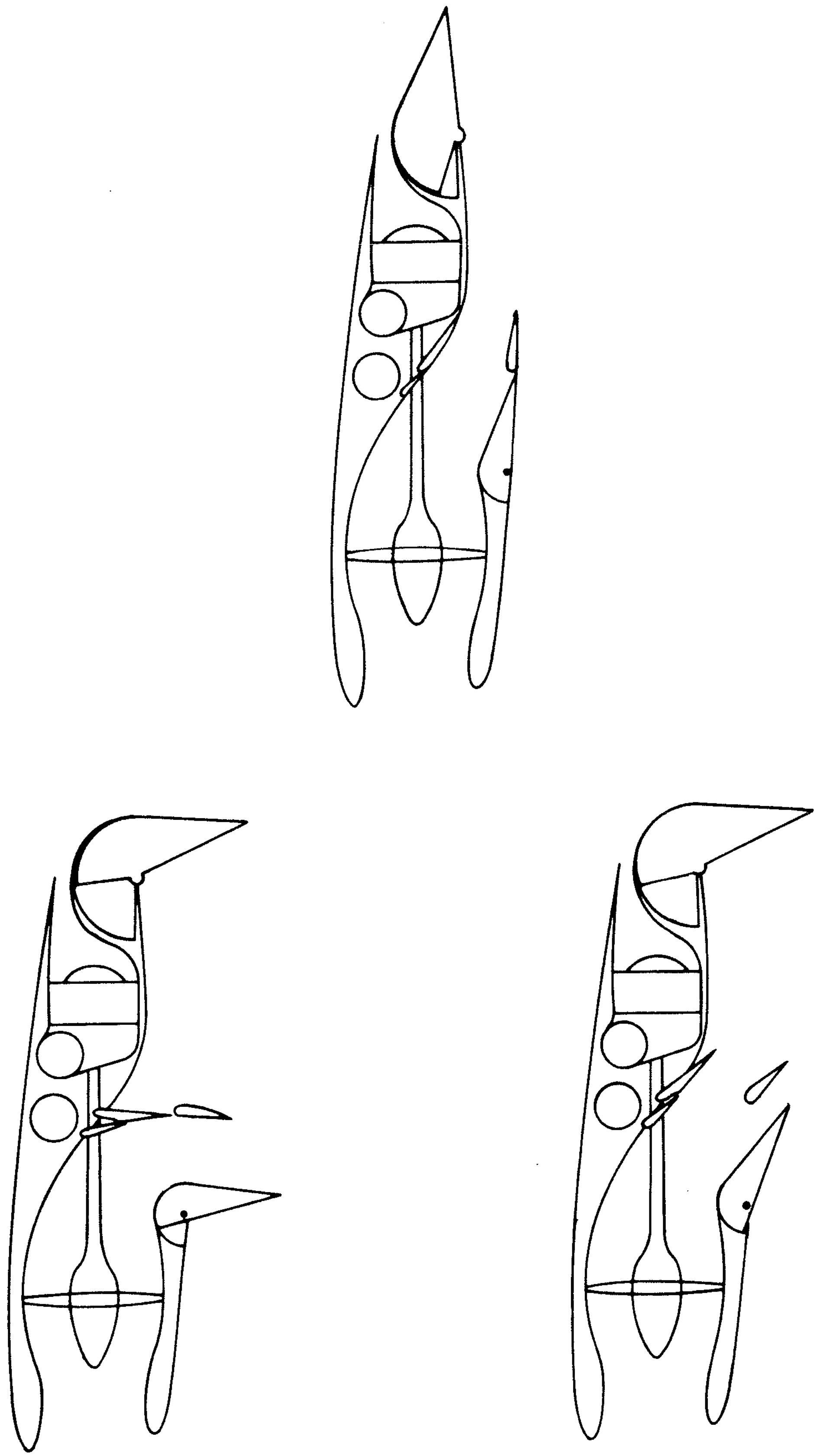

Figure B.5 Propulsive Wing Section Basic Configurations A.10, A.11, A.12 and A.13

C. FAN INLET CONFIGURATION

The ADAM I fan inlet configuration is quite apparent in Figure A.3. Inlet lips had generous radiuses. As mentioned above, a test indicated excellent static inlet recovery.

The first ADAM II configuration, as shown in Figure A.4, had round fan inlets with almost ideal internal lines and rather heavily compromised external lines. In the fan inlet design indicated in Figure A.5, external lines were improved with some possible penalty to internal lines. The bluff areas between fans were relieved by applying forward-extending protrusions, emulating the treatment of the twin fan nacelles of the B-52H. This inlet did not lend itself to geometry variation, which might have been found necessary for good static inlet performance.

By the time the configuration of Figure A.7 was designed (Appendix D.4), straight, two-dimensional fan inlet lips with optimum external lines had been agreed upon. Variable geometry could be employed if necessary. The wisdom of this decision was confirmed in the static inlet test (Appendix B.7), which showed that it was possible to achieve excellent internal aerodynamics performance with this approach. Unless this inlet encounters unanticipated difficulties at high speeds, variable geometry will not be needed.

All of the earlier ADAM II designs had protrusions of the tail booms extending ahead of the fan inlets. At one time they were considered desirable for high speed aerodynamic considerations. At one stage of design growth the main landing gear wheels were housed in the booms and retracted forward, occupying the space provided by the protrusions. A more extensive study (Appendix D.6) showed that it was preferable to retract the main gear wheels aft into the booms.

In the ADAM III configurations shown in Figures A.12 and A.13, the main gear was located in the fuselage. It had been concluded by this time that there was no aerodynamic justification for having the protrusions in front of the booms and they were discarded.

D. TAIL CONFIGURATION

The first ADAM I wind tunnel model had conventional horizontal and vertical tails as shown in Figures A.1 and D.1. Low speed wind tunnel tests (Appendix B.1) showed that the centerline vertical tail performed well, providing adequate directional stability and rudder effectiveness throughout the angle of attack range tested. The dihedral effect was positive. But it soon became apparent that any horizontal tail placed behind a propulsive wing would be relatively ineffective at providing static longitudinal stability. The reason is that the flow through a propulsive wing is deflected so positively that changes in angle of attack of the wing have very limited effect upon the effective angle of attack of a horizontal surface located behind the wing. The tail therefore has very limited capability for setting up the restoring moments required to provide static longitudinal stability. The early wind tunnel tests showed that a very high T-tail could stabilize the airplane at angles of attack up to the stall. But once the stall was reached, the separated wake from the stalled wing would engulf the T-tail, destroying its lift and causing a violent port-stall pitch up. The high T-tail configuration shown in Figures A.2 and D.2 was proposed under the Air Force SR-175 unpaid study (Appendix D.1). (The wing dihedral apparent in Figure D.2 was intended to make this small transport more suitable for a rescue mission.) It was con-contended that wing buffeting would provide the pilot with adequate stall warning. If the pilot never stalled the airplane, post-stall pitch-ups would never be a problem. Analyses made subsequently to the SR-175 study indicated that the horizontal tail shown in Figure D.2 would not be nearly large enough.

The early wind tunnel tests (Appendix B.1) also showed that if the outer panels were removed, and if a horizontal tail having a span greater than the wing center section was installed, fairly good stability could be provided. This suggested to the project aerodynamicist that the outboard horizontal tail concept, well-known to NACA, Blohm and Voss, and indeed to Chance Vought Aircraft in the early 1940's, should be a natural adjunct to the propulsive wing concept. The crude configuration shown in Figures D.3a and D.3b was hurriedly fabricated to generate preliminary data concerning the performance of horizontal tail surfaces placed outboard of the wing. The results were definitely encouraging. This led to the adoption of an outboard horizontal tail in the configuration shown in Figures A.3 and D.4, which was a transport proposed under Army unpaid study ASR3-60 (Appendix D.2). It is interesting in retrospect to note that in this design the vertical tails were moved along with the horizontal tails to locations on the tail booms. There were only secondary reasons for doing so. It was somewhat inconvenient to mount vertical tails on the fuselage of an assault transport having large rear-end loading doors.

The adoption of butterfly outboard tails, see Figures A.4, A.5, A.6, A.7 and D.5, was contemplated for some time. This approach was finally discarded after an analysis indicated unsatisfactory dynamic stability characteristics.

Separate outboard horizontal and vertical tails were selected for the design shown in Figure A.8. The horizontal tails were unit surfaces and the vertical tails were of fin and rudder design. A horizontal tail of this type having a 30 degree leading edge sweep shown in Figure D.6 was tested under Army Research Office - Durham sponsorship (Appendix B.5). This horizontal tail proved to be highly effective, but only over limited ranges of airplane angle of attack. Being effective, the tail loaded itself up and stalled. Changes in tail incidence would move the range of satisfactory performance, but would not widen it. Very little was learned about vertical tails on this semi-span reflection-plane model which could not be yawed.

Figure D.7 depicts the Air Force-Army-NASA Langley Hi/Lo Model (Appendix B.6) with its original tail configuration. As soon as testing was started, in a shake-down test at the contractor's plant, it became apparent that the outboard vertical tails were performing unsatisfactorily. A low speed, high-power condition, and a moderate speed high angle of attach condition would both generate swirling inflows over the vertical tail. The tails would load up close to their stalls, opposing each other, with zero degrees of model yaw. As the model was then yawed, the vertical tail on one side would stall, while the vertical tail on the other side "backed down" its lift curve, providing some directional stability in an undesirable manner. Since there had been very little reason for moving the vertical tails out to the booms in the first place, a new single vertical tail was promptly fabricated and mounted in a centerline location on the fuselage as shown in Figure D.8. Extensive tests of this tail at low and high speeds at the NASA Langley Research Center showed that it performed well, with good linearity of C_n vs. β, and with positive although perhaps too strong a dihedral effect.

Outboard horizontal tails with 30 degrees leading edge sweep encountered the same tail stall problem that had been found previously in the tests of the semi-span model. It was therefore most encouraging to find that outboard horizontal tails with 60 degrees leading edge sweep performed well at all airplane angles of attack. Independent tests by NASA Langley of a similar propulsive wing model also indicated satisfactory performance for horizontal outboard tails having a 60 degree leading edge sweep.

The tails on the Langley Hi/Lo model were too small to provide adequate stability at normal center of gravity locations (e.g. .25c). Calculations were made to determine the proper sizing of the horizontal and vertical tails. The model as it would appear with properly sized tails is shown in Figure D.9. A review of these stages of evolution of the tail configuration is shown in Figure D.10.

Studies were then made of the application of ADAM concept airplanes to close air support missions (Appendix D.9). Presentations on the results were made to a number of military user activities. Several of those attending these presentations made the very valid observation that a single hit at the juncture of the unit horizontal tail and the tail boom might knock the tail off the airplane, which would, of course constitute crippling damage. Therefore, the design shown in Figure D.11 is being studied. The boom is of multiple span construction. The elevator is mounted on a fairly long hinge axis. This design should be able to survive a number of hits of small arms fire. It has not as yet been tested in a wind tunnel.

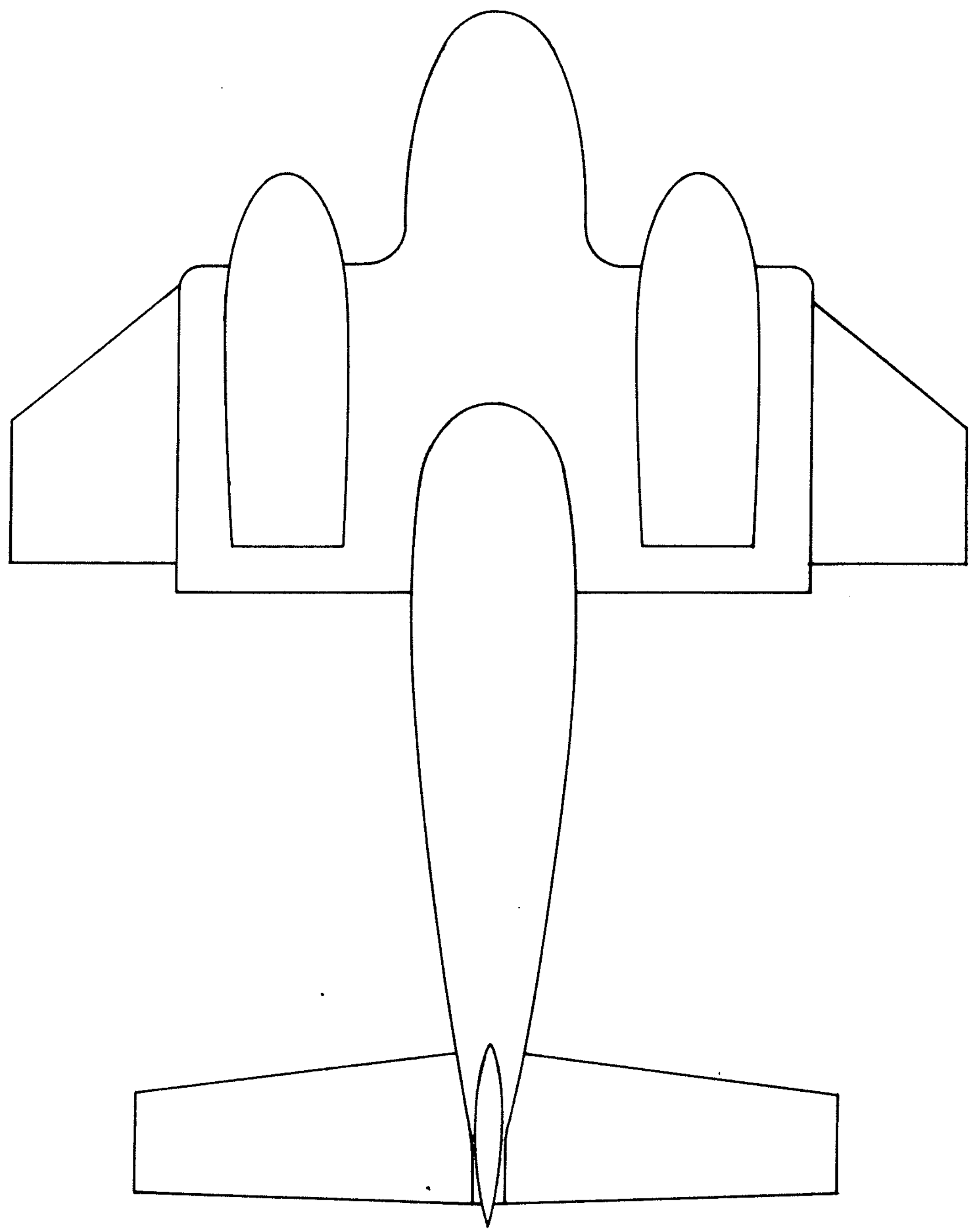

Figure D.1 Tail Configuration Basic Configuration A.1

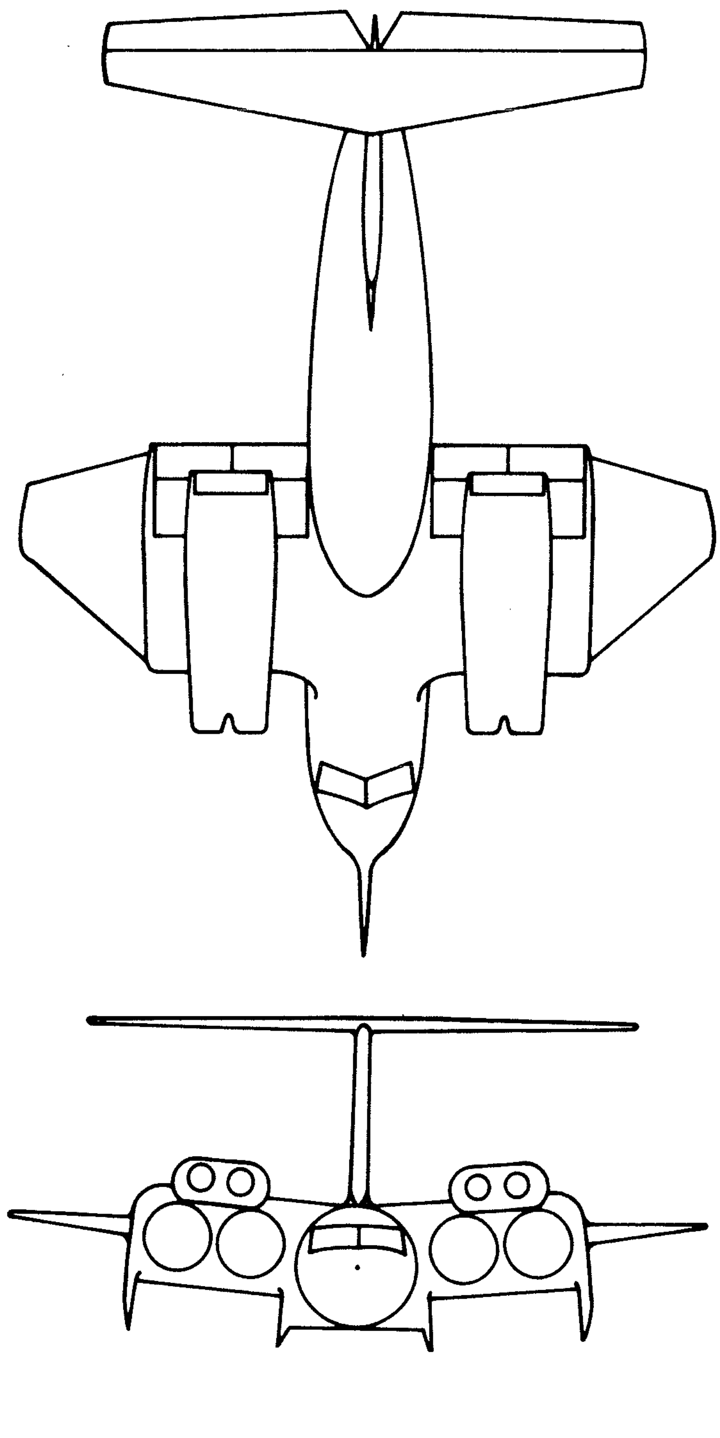

Figure D.2 Tail Configuration Basic Configuration A.2

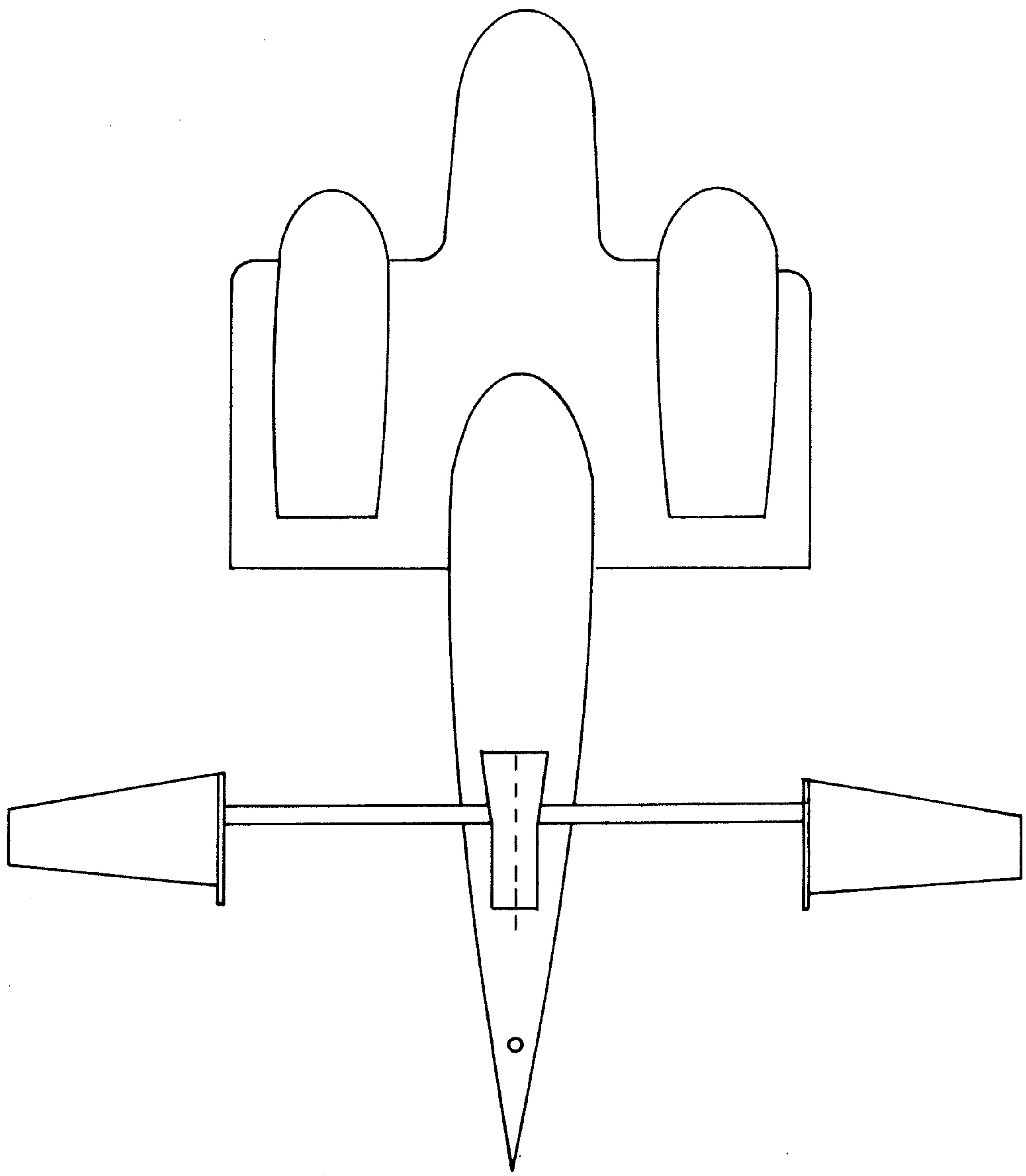

Figure D.3.a Tail Configuration Wind Tunnel Model

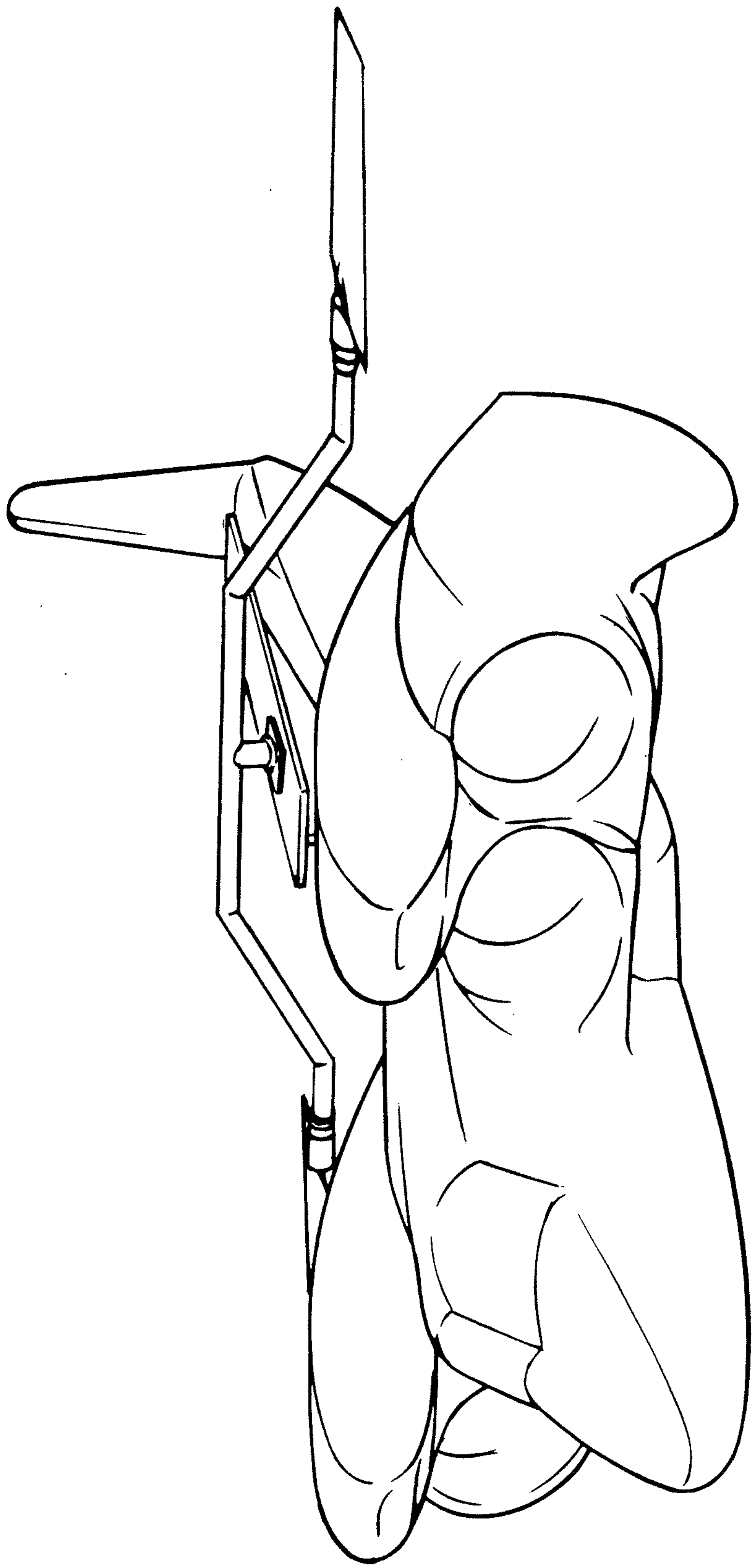

Figure D.3.b Tail Configuration Wind Tunnel Model

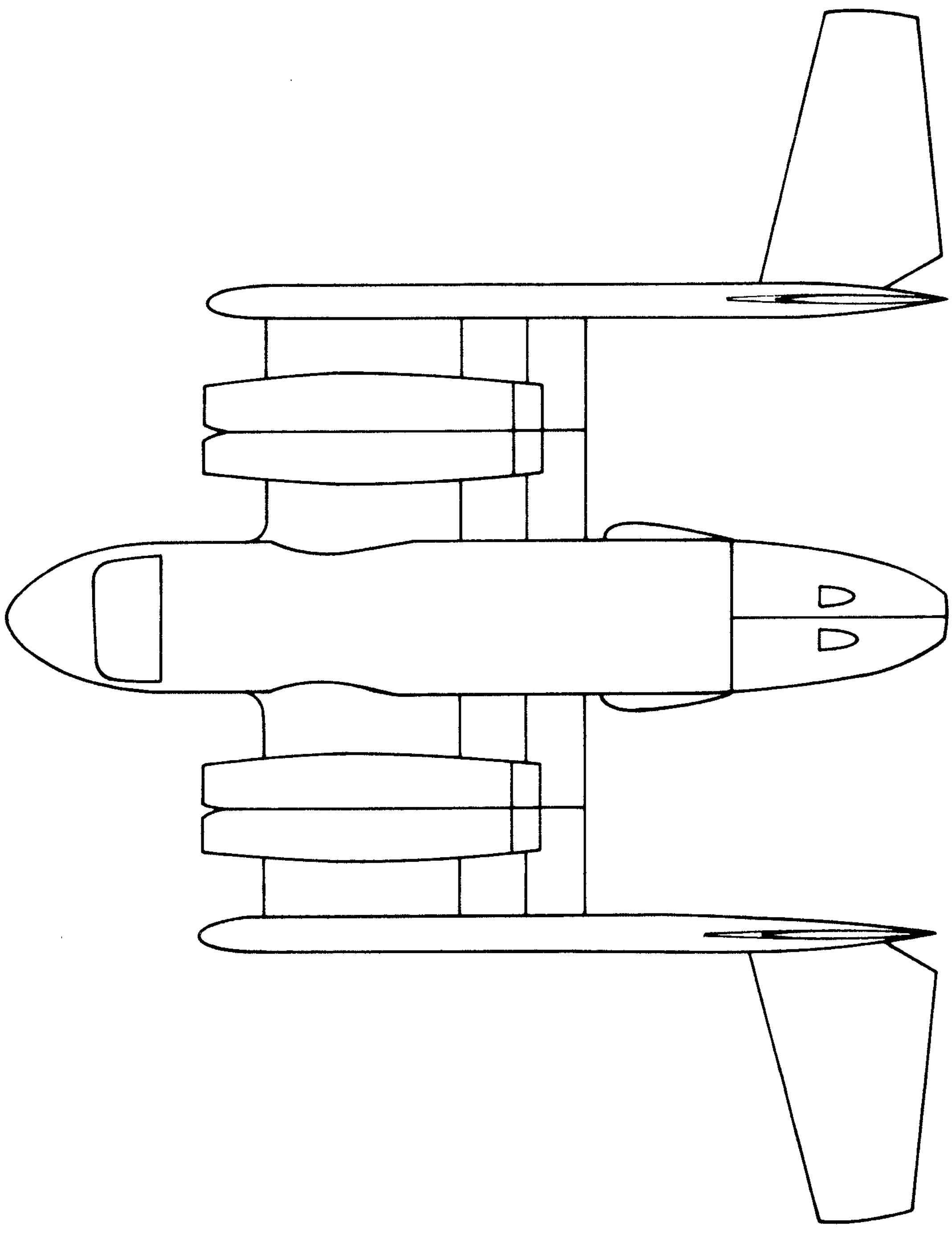

Figure D.4 Tail Configuration Basic Configuration A.3

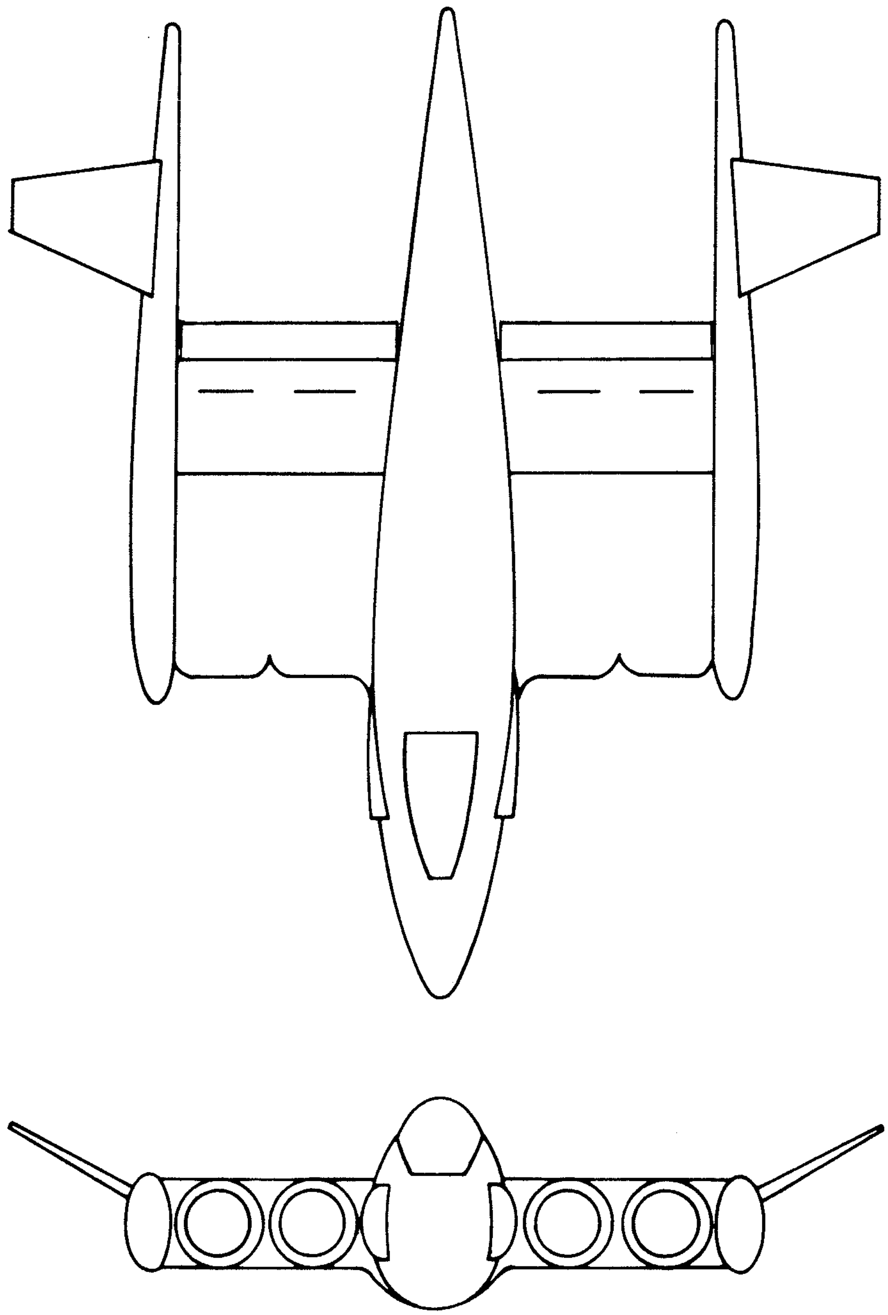

Figure D.5 Tail Configuration Basic Configuration A.4

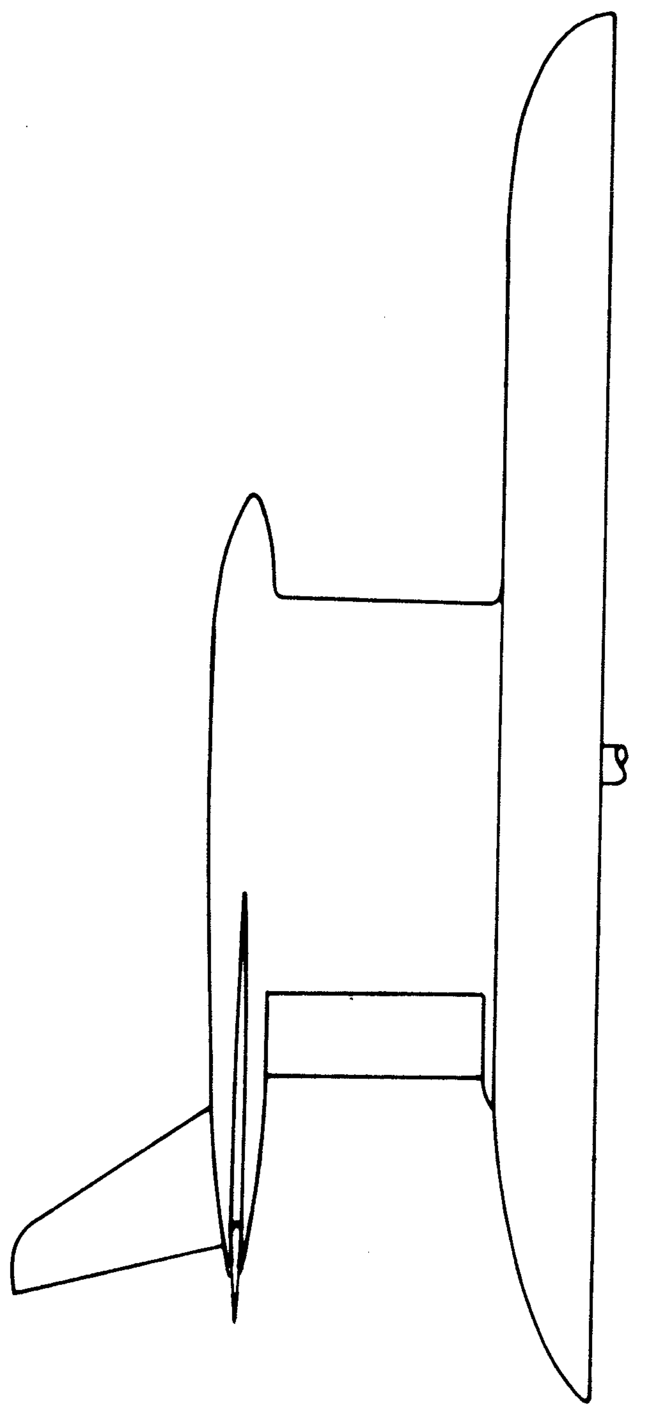

Figure D.6 Tail Configuration Wind Tunnel Model

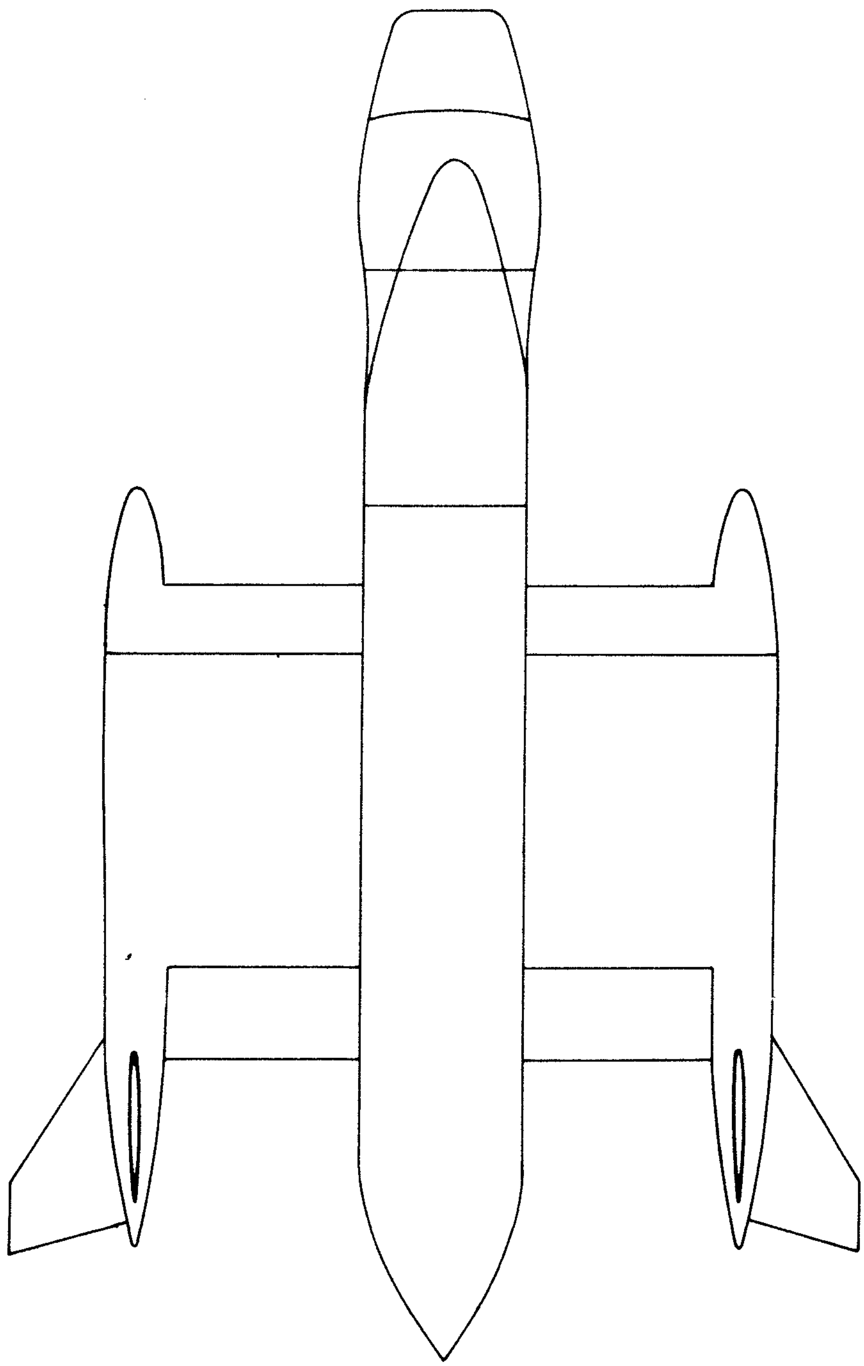

Figure D.7 Tail Configuration Wind Tunnel Model

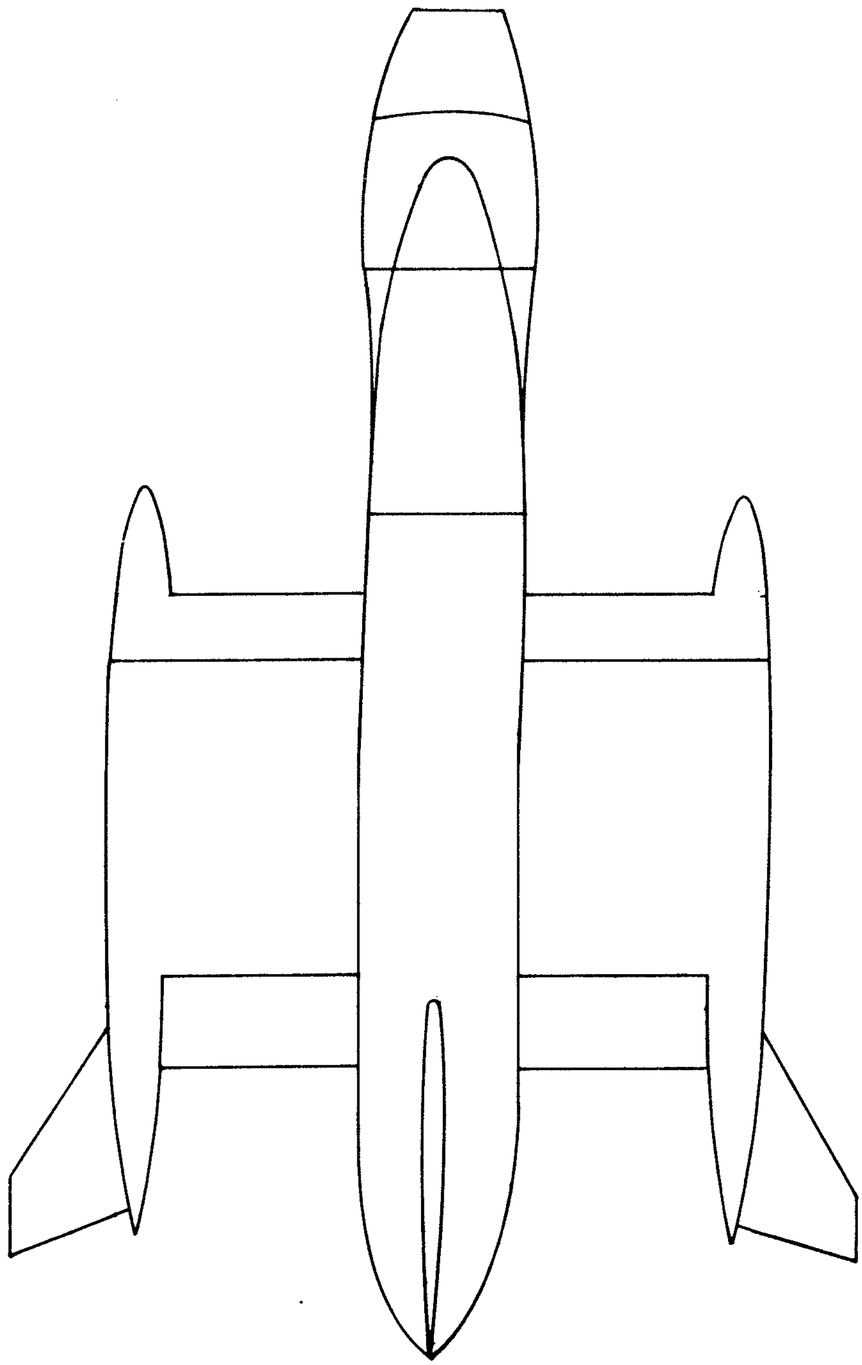

Figure D.8 Tail Configuration Wind Tunnel Model

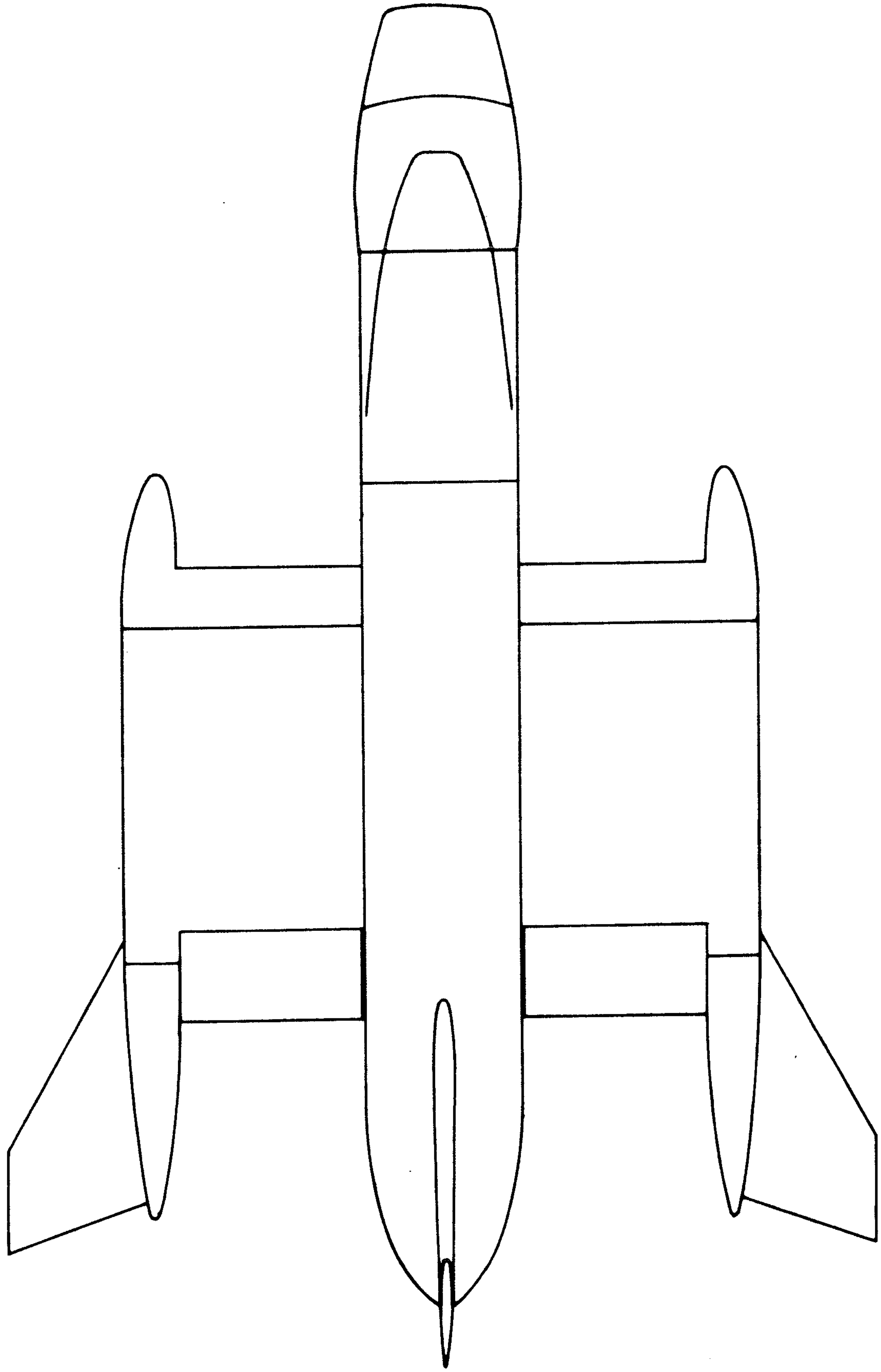

Figure D.9 Tail Configuration Wind Tunnel Model

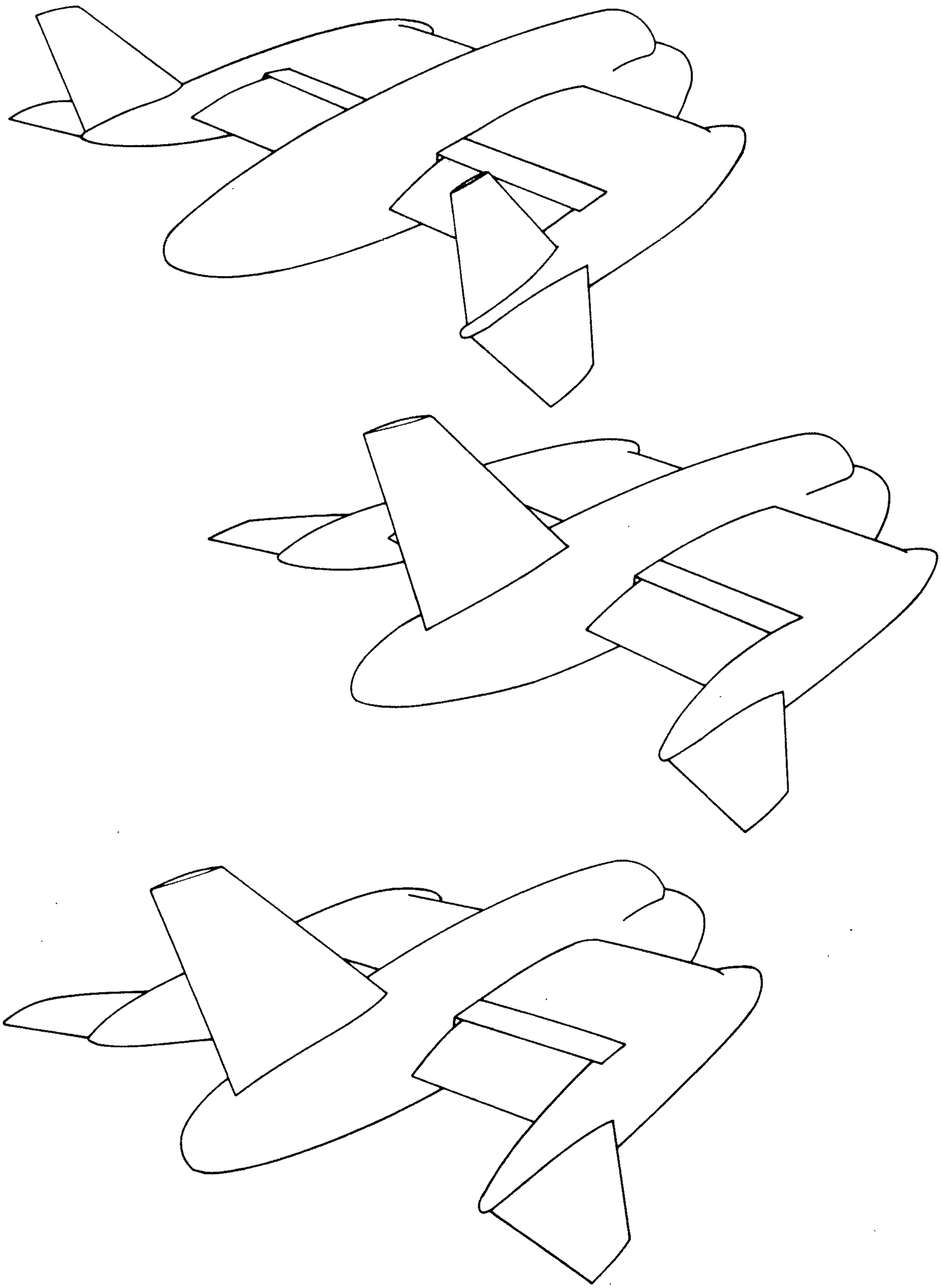

Figure D.10 Tail Configuration Review Wind Tunnel Model Review

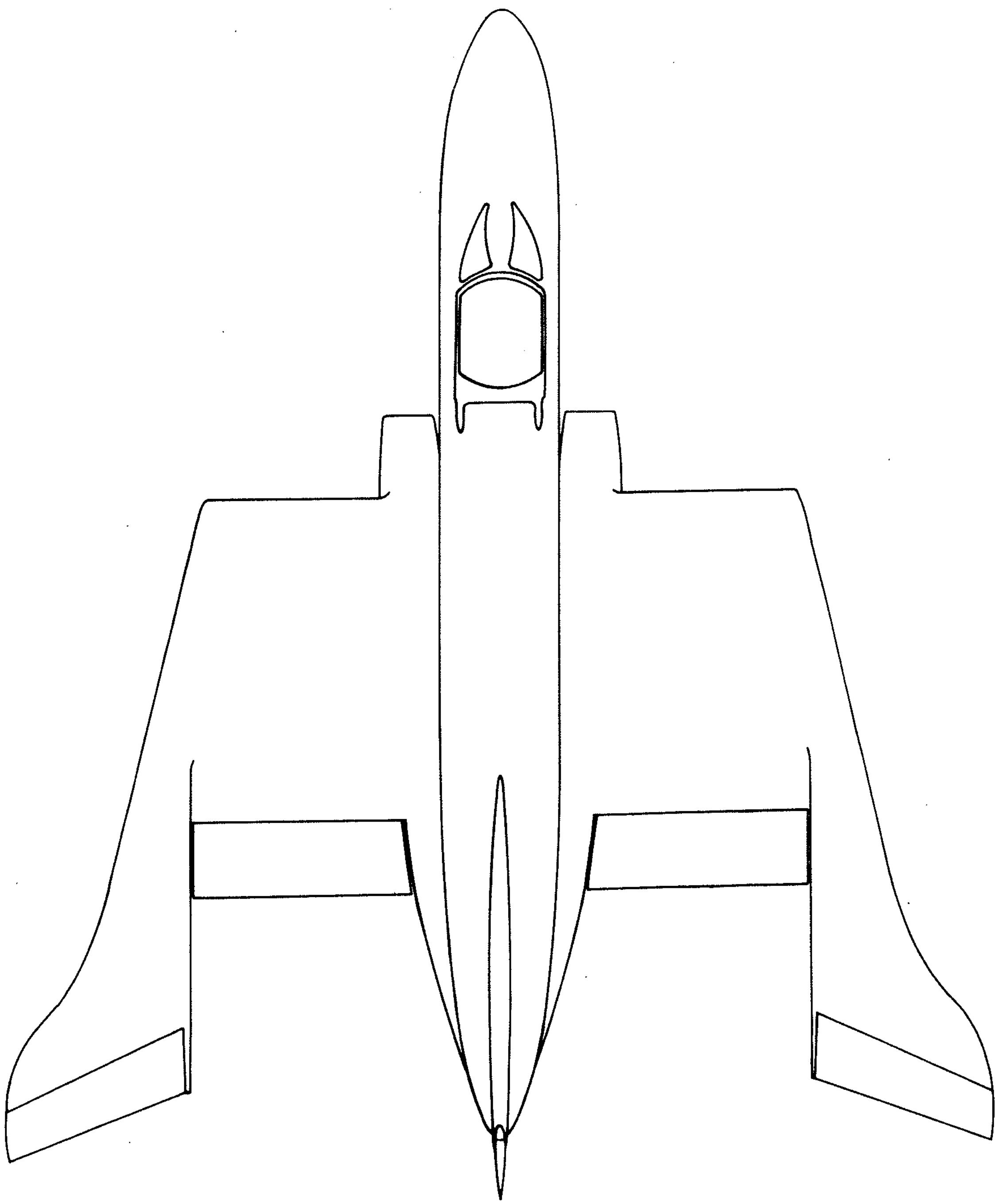

Figure D.11 Tail Configuration Basic Configuration A.11

E. HOVER PITCH CONTROL SYSTEM

The manner in which pitch trim and control is obtained during the hover mode can markedly influence any V/STOL concept. In the initial ADAM I concept, pitch trim and control was obtained by translation of the main wing fan thrust vector. As shown in Figure E-1, this was accomplished by means of double-jointed moving doors which formed major portions of the walls of the fan ducts. Flow from both fans in one pod were merged and passed through a single vectoring bend. The resultant increase in aspect ratio of the bend was expected to reduce flow losses. Translation of the main jet would provide pitch trim and control with minimum sacrifice of lifting potential. This vectoring arrangement was installed in a twin fan propulsion pod model and tested. Unreported data from this test showed that it was probably possible to attain adequate pitch trim and control authority in this manner. The hydraulic horsepower required to actuate the large, heavily-loaded, double-jointed doors, however, was far greater than could be tolerated, and this method of obtaining pitch trim and control was abandoned.

Early ADAM II configurations bled off a portion of the fan discharge flows and ducted them to differentially variable nozzles at the front and rear extremities of the airplane. This arrangement is illustrated in Figure E.2. It was hoped that this approach would minimize the loss of lifting potential entailed in providing pitch trim and control authority. The power required to actuate the nozzles would have been very nominal. As shown in Figure E.3, the flows bled from all wing fans were diffused and discharged into a plenum. Ducts with bell-mouth entries led fore and aft from this plenum. The front duct went directly to the front nozzle. The rear duct discharged into a plenum in the rear part of the fuselage. The rear nozzle discharged from this plenum to the exterior.

The design shown in Figure E.3 left much to be desired. It was found to be very difficult to design the duct system, operating on low pressure fan air, with acceptably small flow losses. A large amount of internal volume was occupied by pitch control ducting. This became increasingly disadvantageous as gas generator technology improved and airplanes of any given size became capable of lifting greater useful loads. And finally, the center of gravity, which still had to be aligned with the wing hover thrust vector, remained at a more rearward location than was desired.

An intensive study of an LTV design for a Fan-in-Wing surveillance airplane revealed how much the nose fan contributed to this VTOL concept. Pitch trim and control in the hover mode was obtained by gas power exchange, or power transfer, between the nose fan and the wing fans. The gas power exchange principle is discussed in Appendix E. Its application to pitch trim and control in the hover mode is depicted schematically in Figure E.4. This approach was being promoted by the General Electric Company at the time.

It was decided to employ a vertical axis, tip-turbine nose fan in an ADAM II concept surveillance airplane similar to that in Fan-in-Wing airplane. The resulting configuration is shown in Figure E.5. The consequent improvement in wing structural load paths. Alleviation of the fan flow vectoring problem, and elimination of restraints on Center of Gravity location were most gratifying. One additional benefit was that the reduction in disc loading resulting from adding the nose fan disc area to the lifting system permitted as increase of some 8% in the permissable VTOL take-off gross weight rating.

The wind tunnel tests on the ARO-Durham semi-span model (Appendix B.5) showed that very high lift coefficients could be attained at low cruise speeds by deflecting the trailing edge flap and establishing a jet flap effect. The high lift coefficients were accompanied by strong nose down pitching moments which could not be trimmed out by aerodynamic control surfaces of reasonable size. Therefore it was decided to convert the nose fan into a forward-facing, shaft-driven, continuously running fan as shown in Figure E.6. The turbine driving this fan was located back with the other hot components, driving the fan through a long shaft. With continuous operation of the fan, pilot work-load was minimized. The pilot could fly all the way from a full hover to maximum speed with no step changes other than lifting the landing gear. The fan was immediately available at all times to enhance inflight maneuverability. STOL distance was decreased about 20%. Thrust augmentation ratio was improved at speeds up to cruise speeds. At cruise and high speeds, fuel consumption was about the same whether the nose fan was left in operation or not.

The forward-facing nose fan met with considerable resistance on the part of various user activities. The long shaft was considered to be a potential hazard. The nose fan occupied valuable space in the front of the airplane, leaving no suitable location for a radar dish. A recent change relocating the gas generators from the belly of the fuselage to the wing root opened up the possibility of reducing fuselage frontal area, but the space required by the forward-facing nose fan precluded doing so.

Therefore, the second close support application study was predicated upon a design which reverted to a tip-turbine nose fan. The fan axis was inclined ahead of vertical as shown in Figure E.7 to improve inlet flow conditions. Another configuration, shown in Figure E.8, is also under study. In this arrangement, the pilot is moved as far forward as possible and a vertical axis fan is mounted in the fuselage behind the pilot. With the full depth of the fuselage available for the fan duct, it is expected that inlet and outlet vectoring arrangements can be derived which will permit use of this front fan at moderately high flight speeds, enhancing STOL performance and in-flight maneuverability. This design is the ultimate in affording the user freedom to configure the front end of the airplane as he desires.

Other types of hover pitch trim and control arrangements have been studied. These include the use of compressor bleed air jets, hot gas jets, and auxiliary lift engines. These arrangements can all be made to work, but to date, none of them has appeared to be advantageous to the nose fan with gas power exchange.

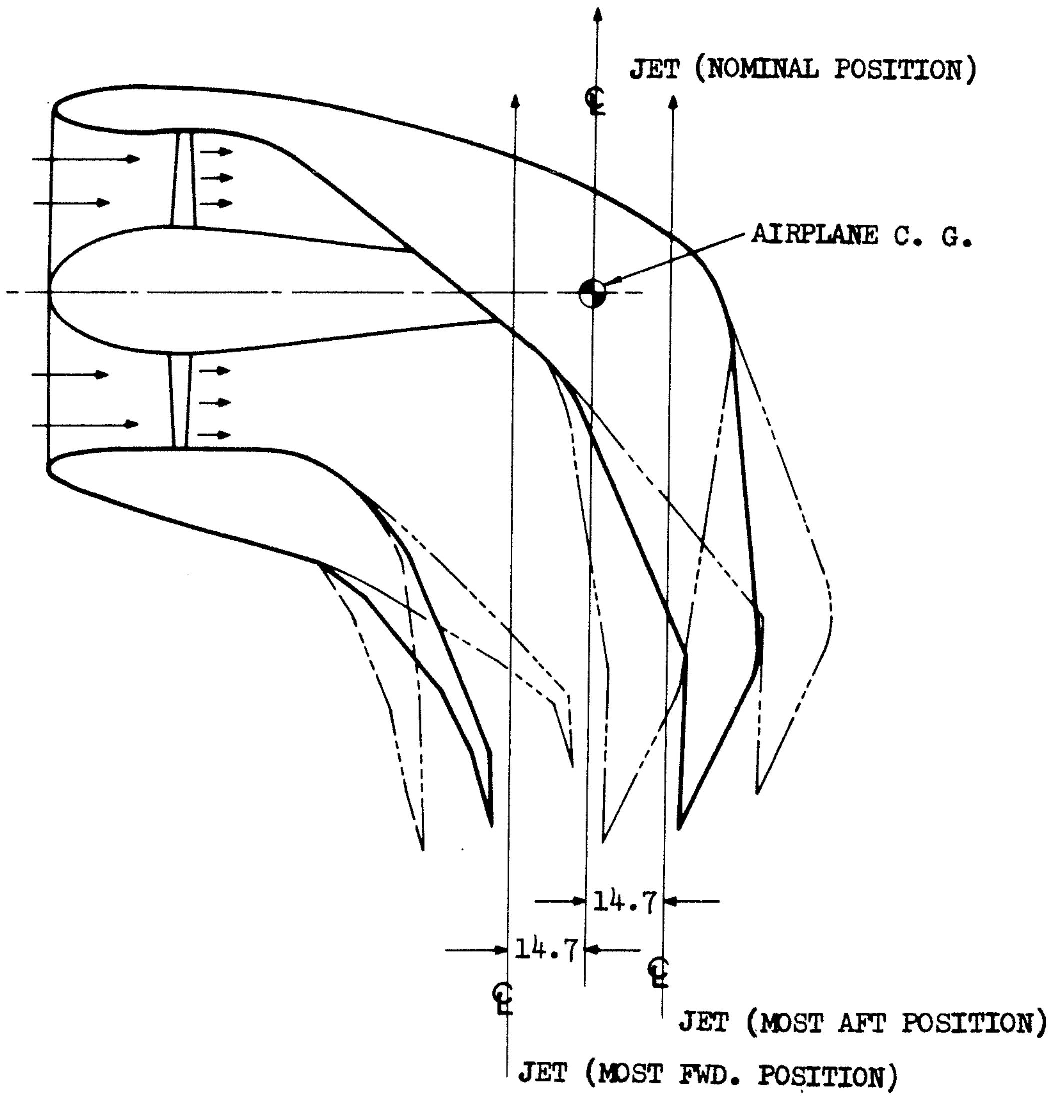

Figure E.1 Hover Pitch Control System Basic Configurations A.1, A.2 and A.3

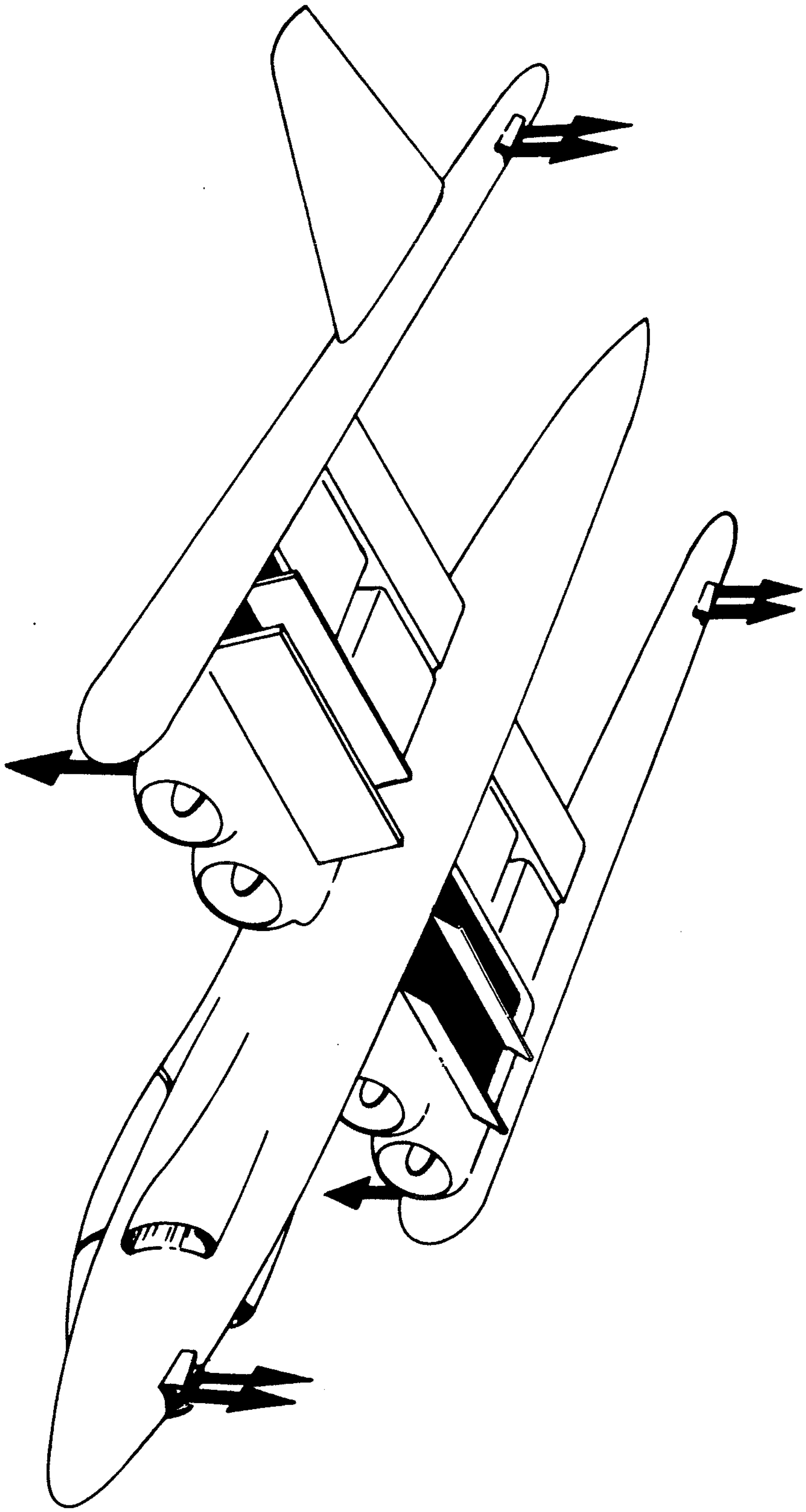

Figure E.2 Hover Pitch Control System Basic Configuration A.4

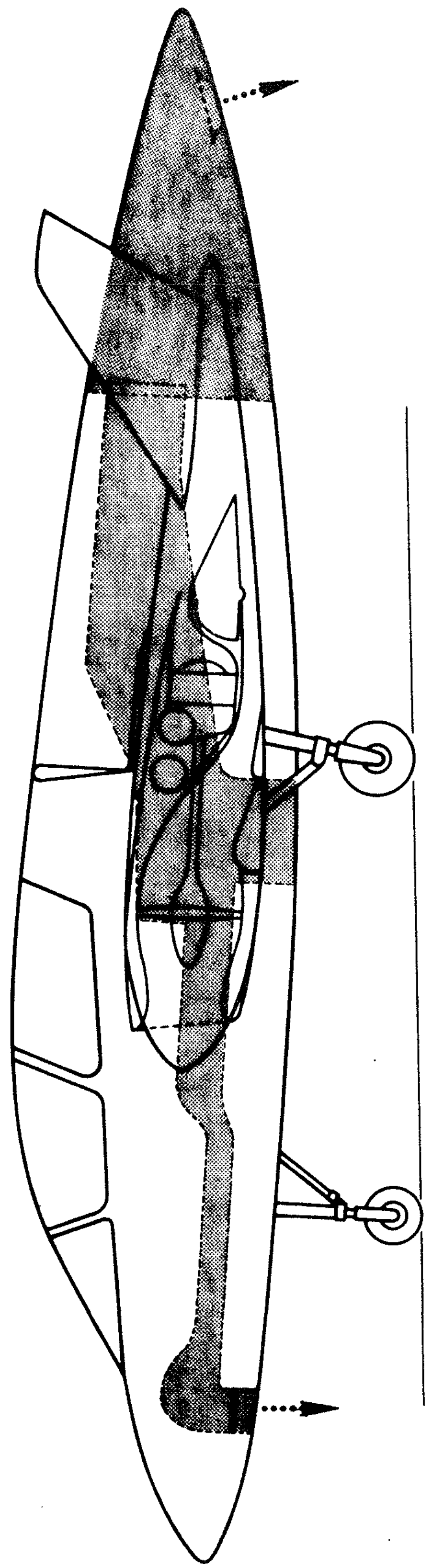

Figure E.3 Hover Pitch Control System Basic Configuration A.5

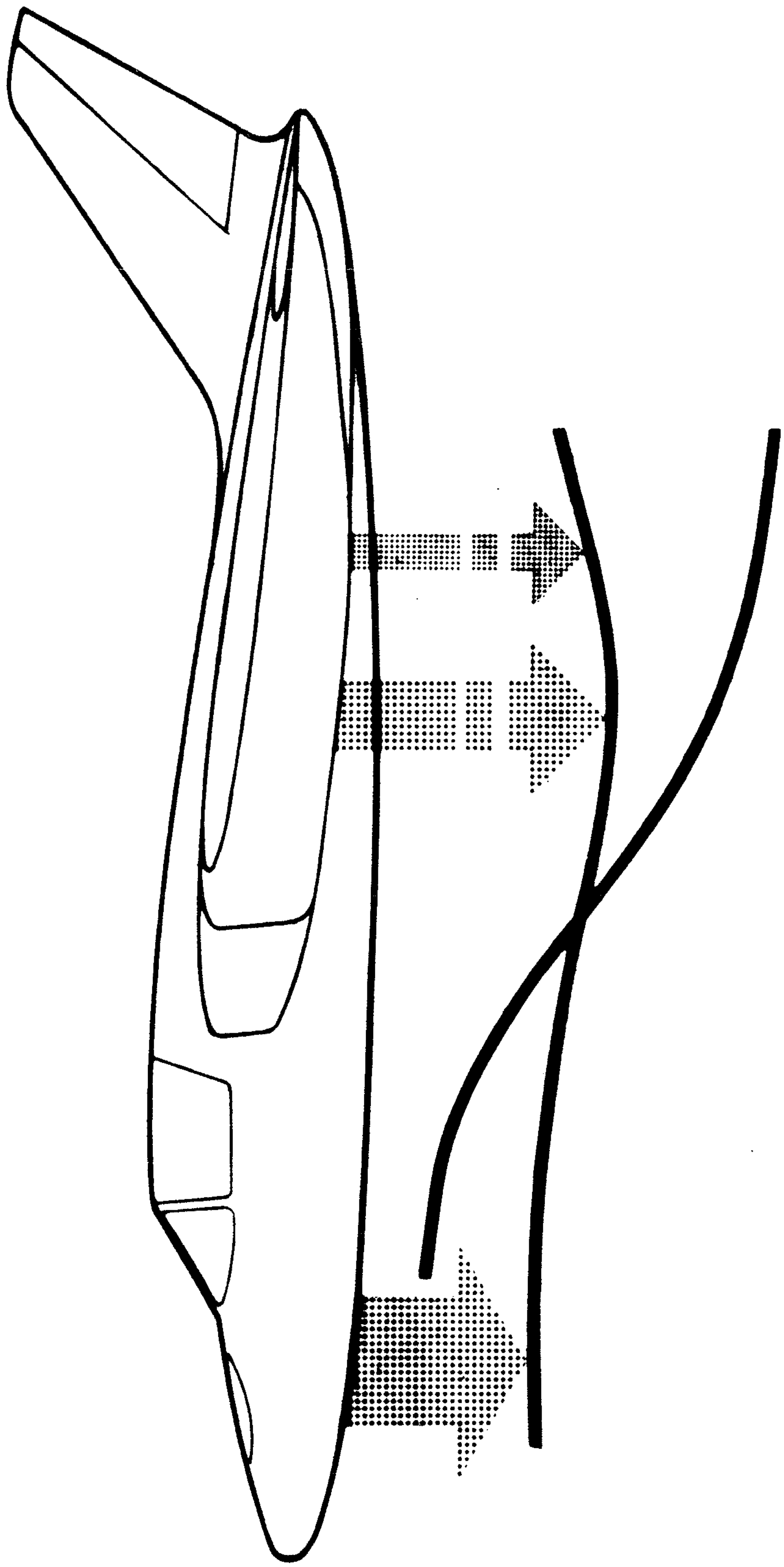

Figure E.4 Hover Pitch Control System Schematic of Gas Power Exchange Approach

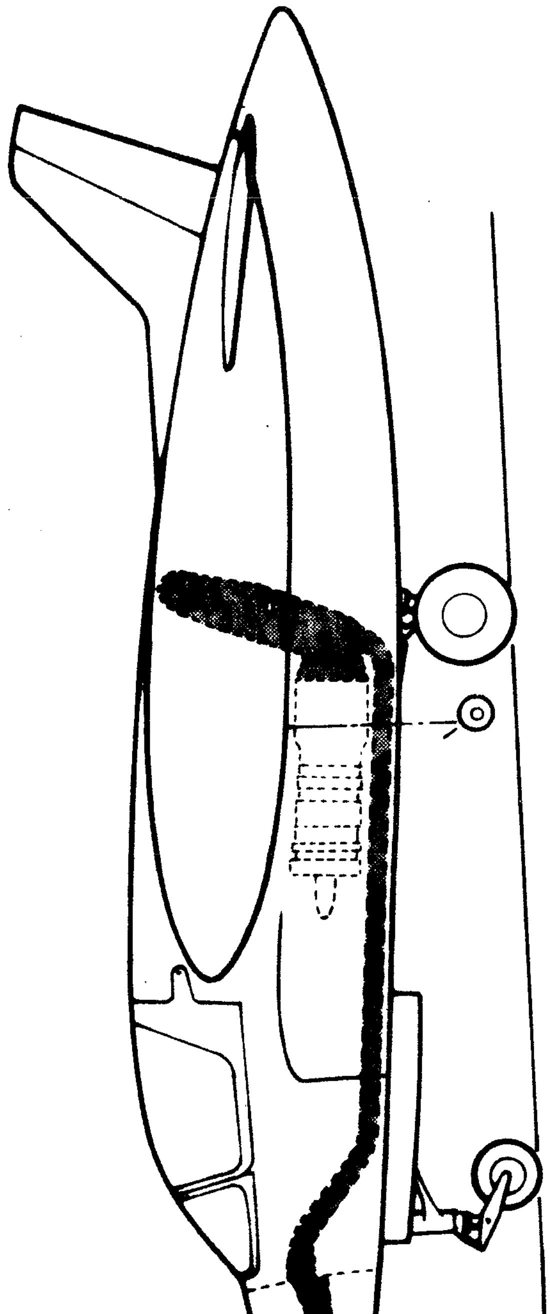

Figure E.5 Hover Pitch Control System Basic Configuration A.8

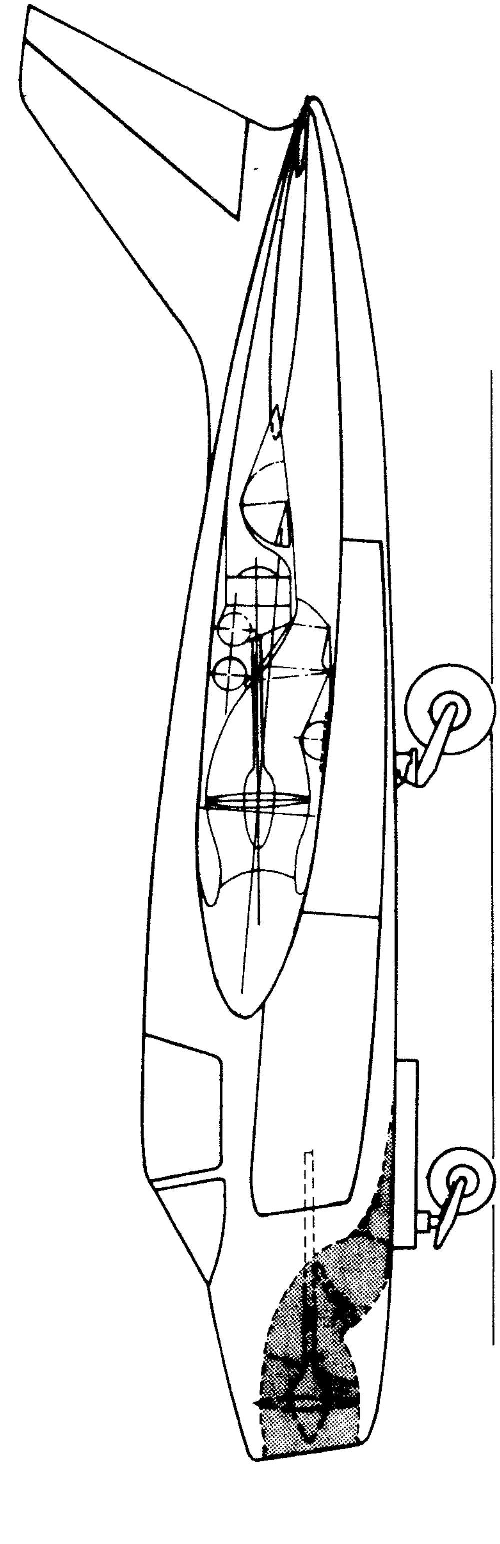

Figure E.6 Hover Pitch Control System Basic Configuration A.9

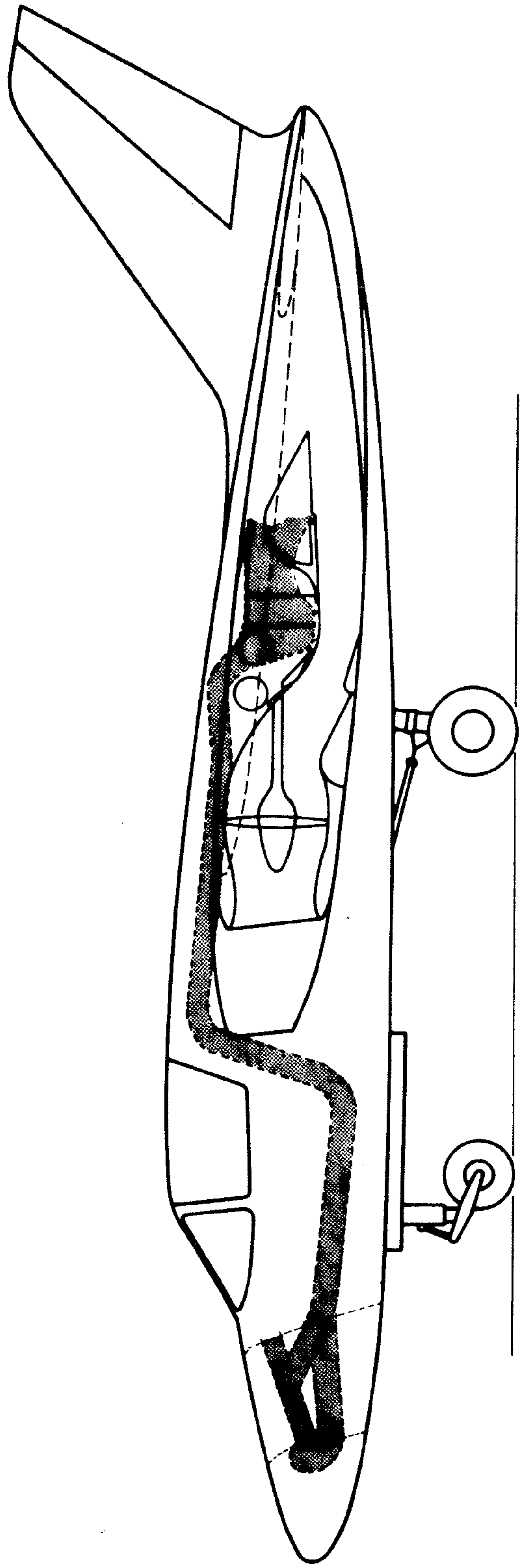

Figure E.7 Hover Pitch Control System Basic Configuration A.12

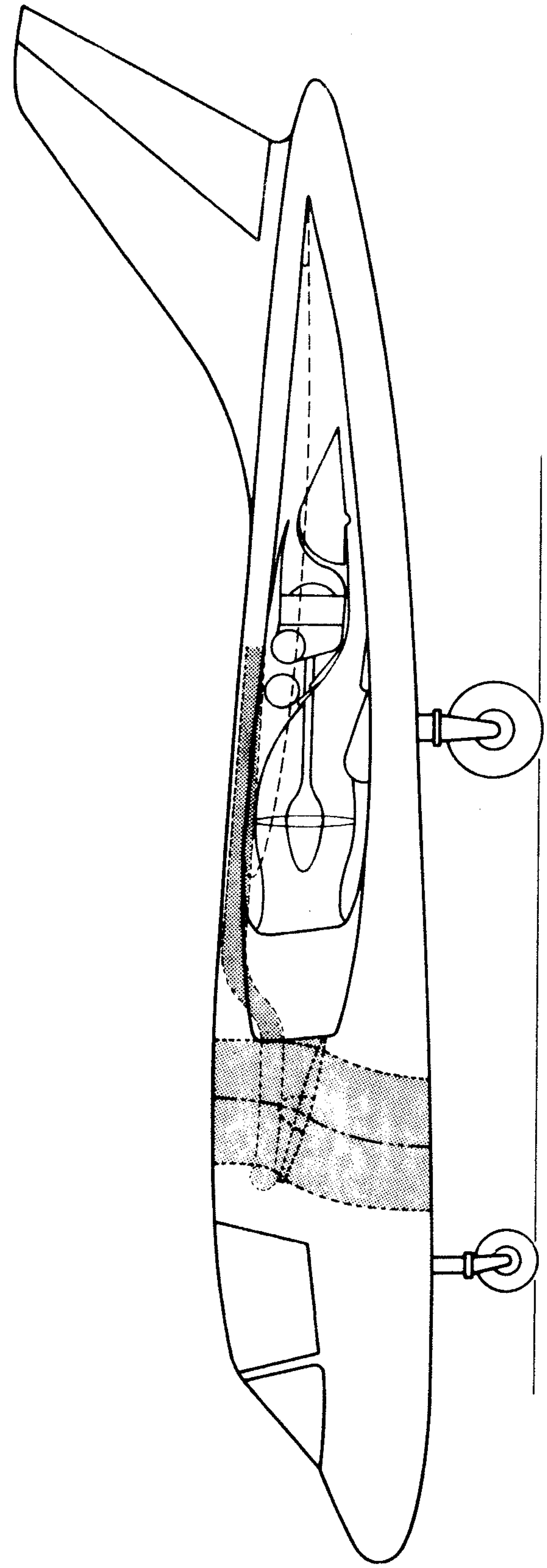

Figure E.8 Hover Pitch Control System Basic Configuration A.13

F. HOVER ROLL CONTROL SYSTEM

The original ADAM I concept envisoned obtaining hover roll control by varying the fan nozzle geometry so as to move the resultant thrust vectors on each side in a lateral direction by actuation of the nozzle doors as indicated in Figure F.1. At this time, no information was available concerning the magnitude of the hover control authority required. Results of the first configuration tested were not encouraging.

The first ADAM II configurations obtained hover roll control by use of fan bleed air from the hover pitch control bleed air ducting. Downward-facing nozzles at the rear end of the lift and right tail booms could be varied differentially, and upward-facing nozzles in the left and right fan ducts could also be varied differentially. The arrangement is shown in Figure E.2.

By 1963, information on the required magnitude of hover roll control authority was becoming available from other programs. Continuing studies indicated that the gas power exchange system being promoted by the General Electric Company would be most suitable for the ADAM II concept. The gas power exchange principle is discussed in Appendix E. Its application for roll control is depicted schematically in Figure F.2, using differential variation between the wing fans on one side of the airplane versus those on the other side.

Basic configuration A.7 and all subsequent have used gas power exchange for hover roll control. If necessary, maximum roll control may still be obtained by ejecting fan air upward as shown in Figure E.2 to exert momentary downloads.

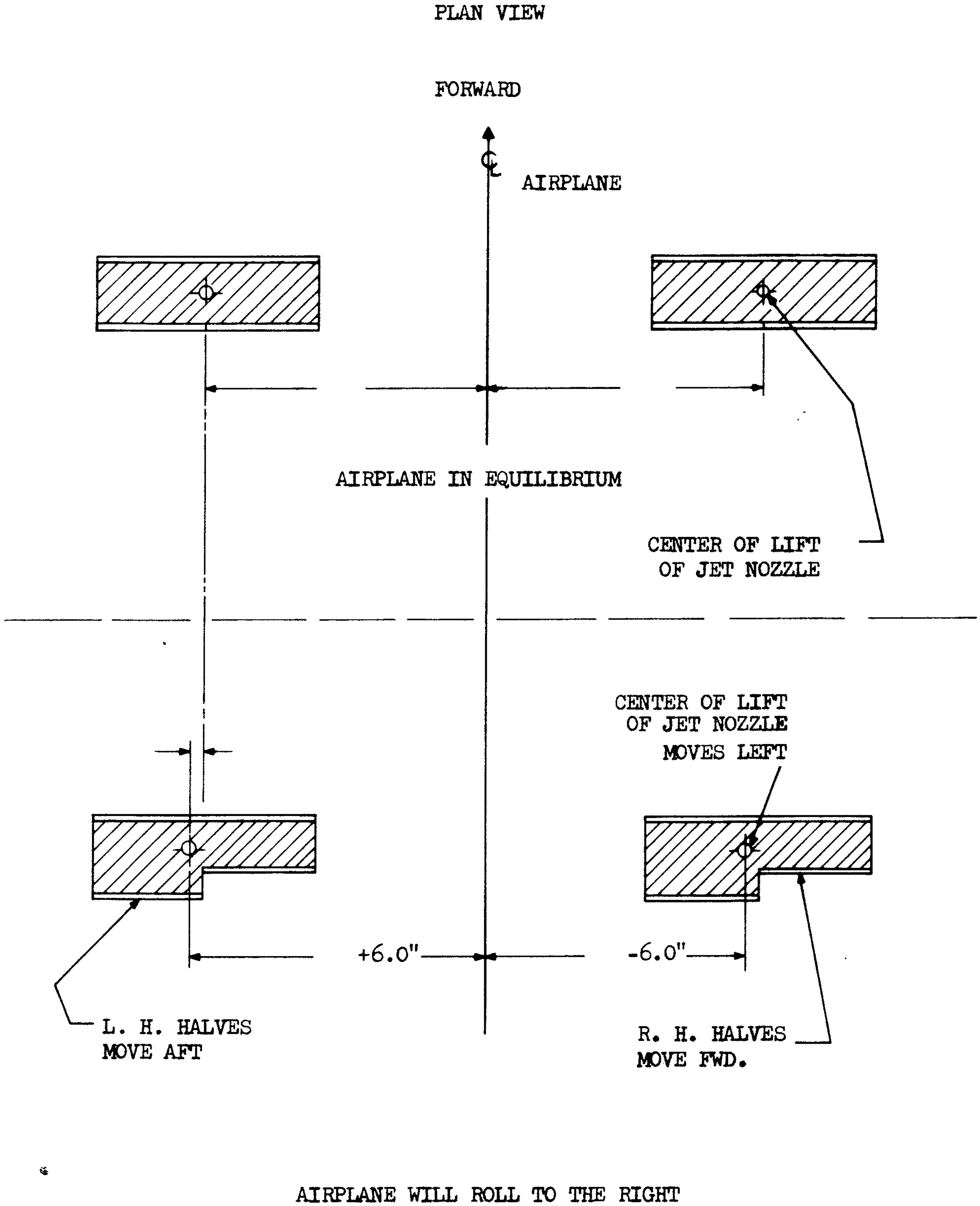

Figure F.1 Hover Roll Control System Basic Configurations A.1, A.2, and A.3

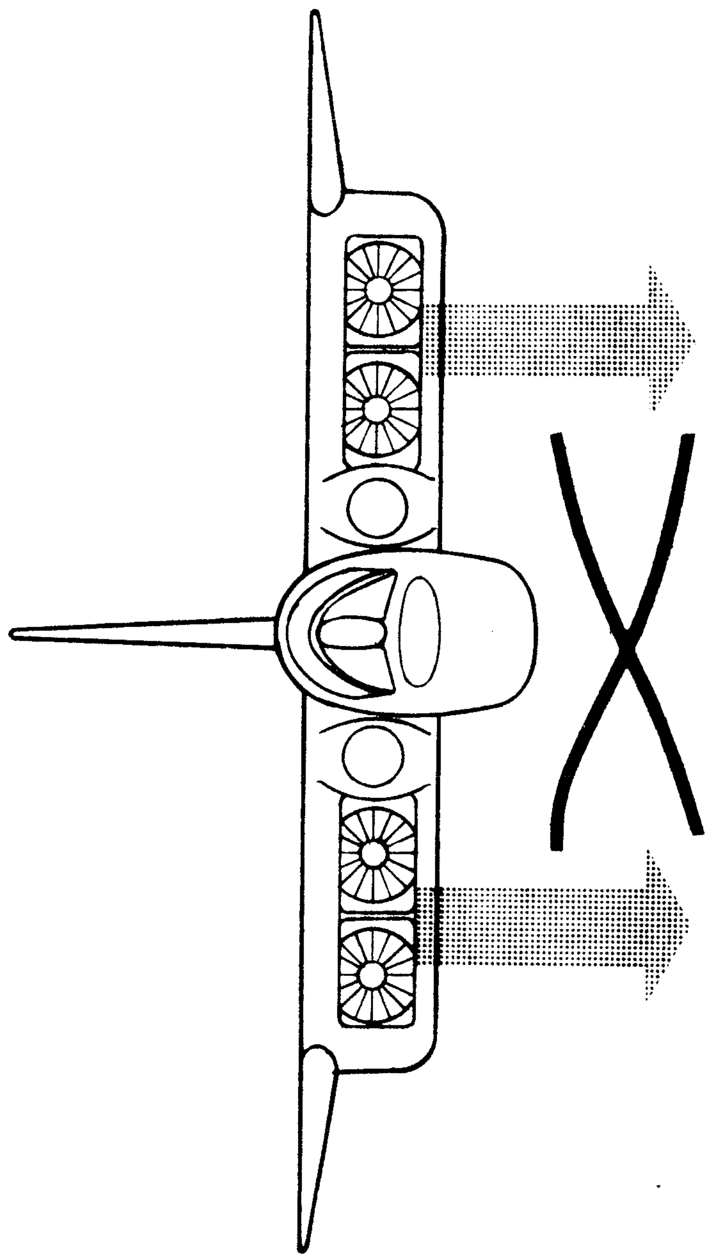

Figure F.2 Hover Roll Control System Schematic of Gas Power Exchange Approach

G. HOVER YAW CONTROL SYSTEM

It has been planned since the start of the project to obtain hover yaw control by differential vectoring of the fan jets from one side to the other. The arrangement is depicted schematically in Figure G.1.

The vectoring doors used are already present in ADAM concept airplanes. Using them to obtain hover roll control in addition to transition vectoring involves only modification of the actuation system.

From simple trigonometry, a 10 degree deflection sets up a horizontal force which is 17% (sine 10 degrees) of the lift thrust, with a loss of only 1% (cosine 10 degrees) in lift thrust.

As is the case for differential vectoring yaw control in other VTOL concepts, yaw and roll control functions are interchanged as thrust is vectored through a transition. Mechanical mixing boxes have satisfactorily performed this interchange in several VTOL airplanes which have been flight tested.

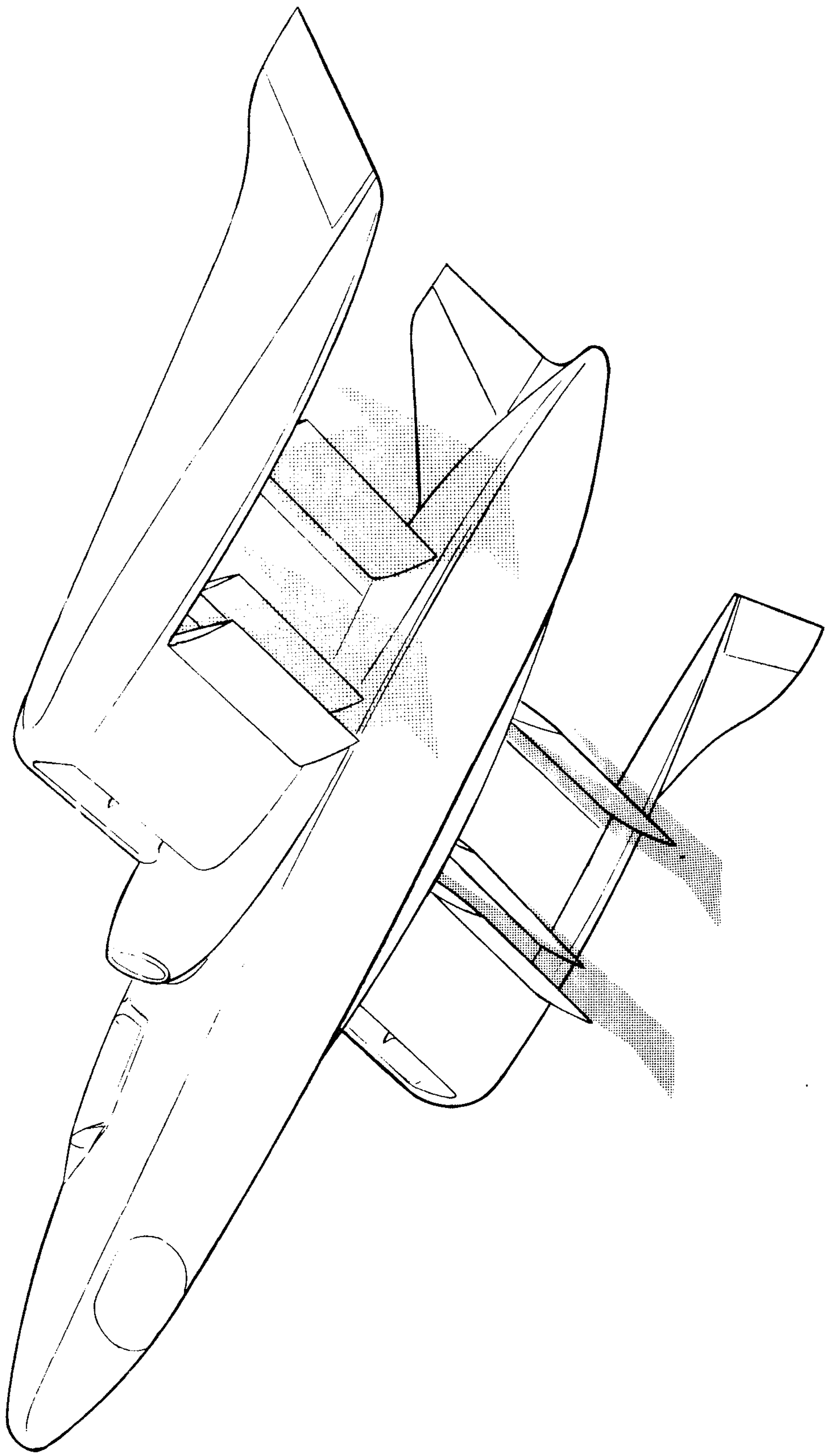

Figure G.1 Hover Directional Control Systems All Configurations

H. GAS GENERATOR LOCATION AND INLET CONFIGURATION

The location of the gas generators in the ADAM I concept, two side-by-side on top of each fan nacelle, is evident in basic configurations A.2 and A.3. Gas generator inlets were short and straight.

In the first ADAM II configuration, the two gas generators were mounted side-by-side in the belly of the fuselage with the ram air entering from the rear as shown in Figure H.1. The gas generator inlets were located high on the fuselage over the wing. Trash ingestion should be at a minimum at this location. The inlet duct had two bends each of approximately 90 degrees. Turning vanes were used to reduce flow losses. These inlet ducts were rather carefully designed. It was found that acceptably high inlet recoveries could be achieved. Blow-in doors were needed for the hover mode.

An attempt was made to use straight-through flow in the inlets as illustrated in Figure H.2. An early basic configuration of this type is shown in Figure A.5. This was in the era when the Center of Gravity of the airplane had to be kept well aft. It was found to be impossible to balance the airplane with the gas generators ahead of the transverse hot gas ducts. Therefore in the next design, as shown in Figure A.6, a reversion was made to the high inlet location with reverse flow through the gas generators.

The incorporation of the nose fan into the concept for hover pitch trim and control permitted the Center of Gravity to be moved forward. Designs up to this time used gas generators of the J85--J60--J52 state-of-the-art. When more advanced gas generators of the GE1--STF240--GMA100 class entered the picture, the lifting capability of any given size ADAM airplane increased substantially. This placed a premium on fuselage volume, and dictated a change back to the gas generator location shown in Figure H.2.

With the now more forward Center of Gravity location, it became possible to balance this configuration.

Contacts with military user personnel early in 1968 revealed valid objections to locating the two gas generators side-by-side. One hit might knock out both engines. At the same time, STOL and loiter performance was assigned more importance, and therefore it became desirable to have more span. The gas generators were accordingly moved out into the wing roots as shown in Figure H.4. Simple short, straight inlets could be used. With this approach, it becomes necessary to use fairings behind the gas generators.

Many other configurations have been examined, particularly for transport studies.

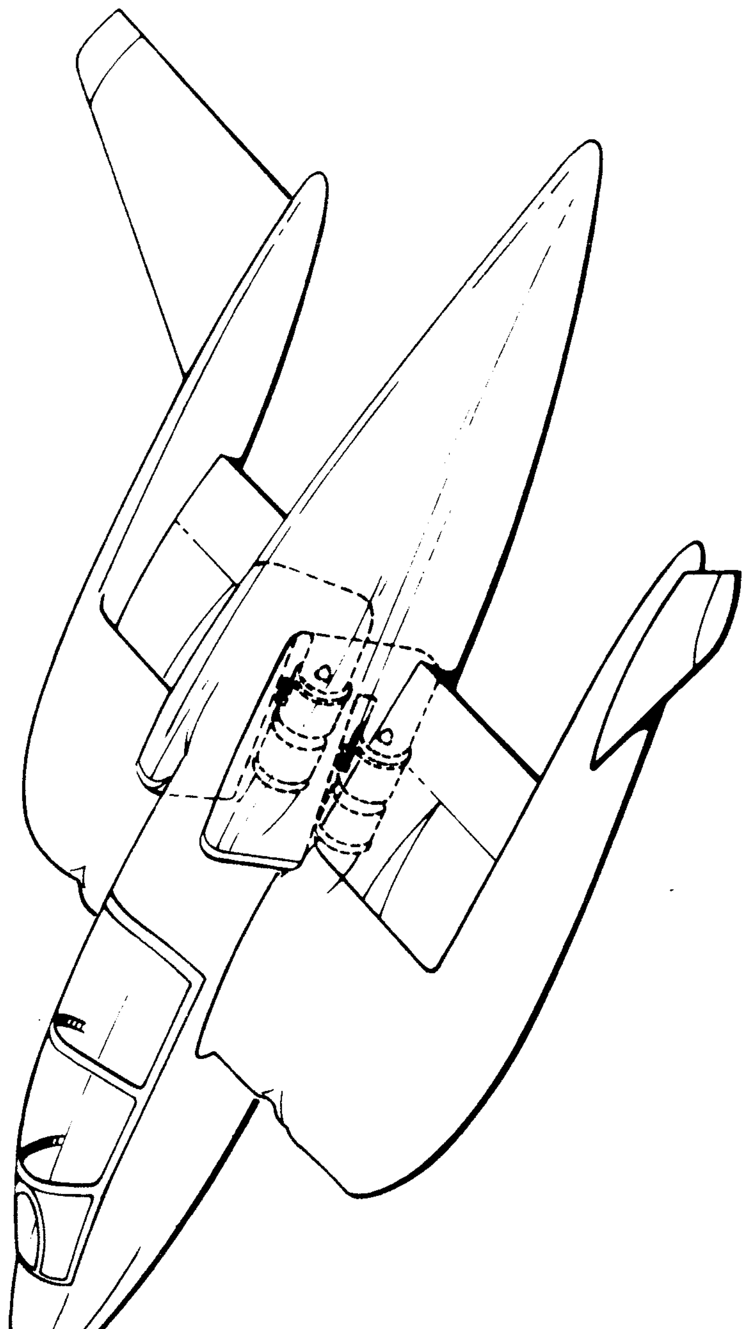

Figure H.1 Gas Generator Location and Inlet Configuration
Basic Configurations A.4, A.6, and A.7

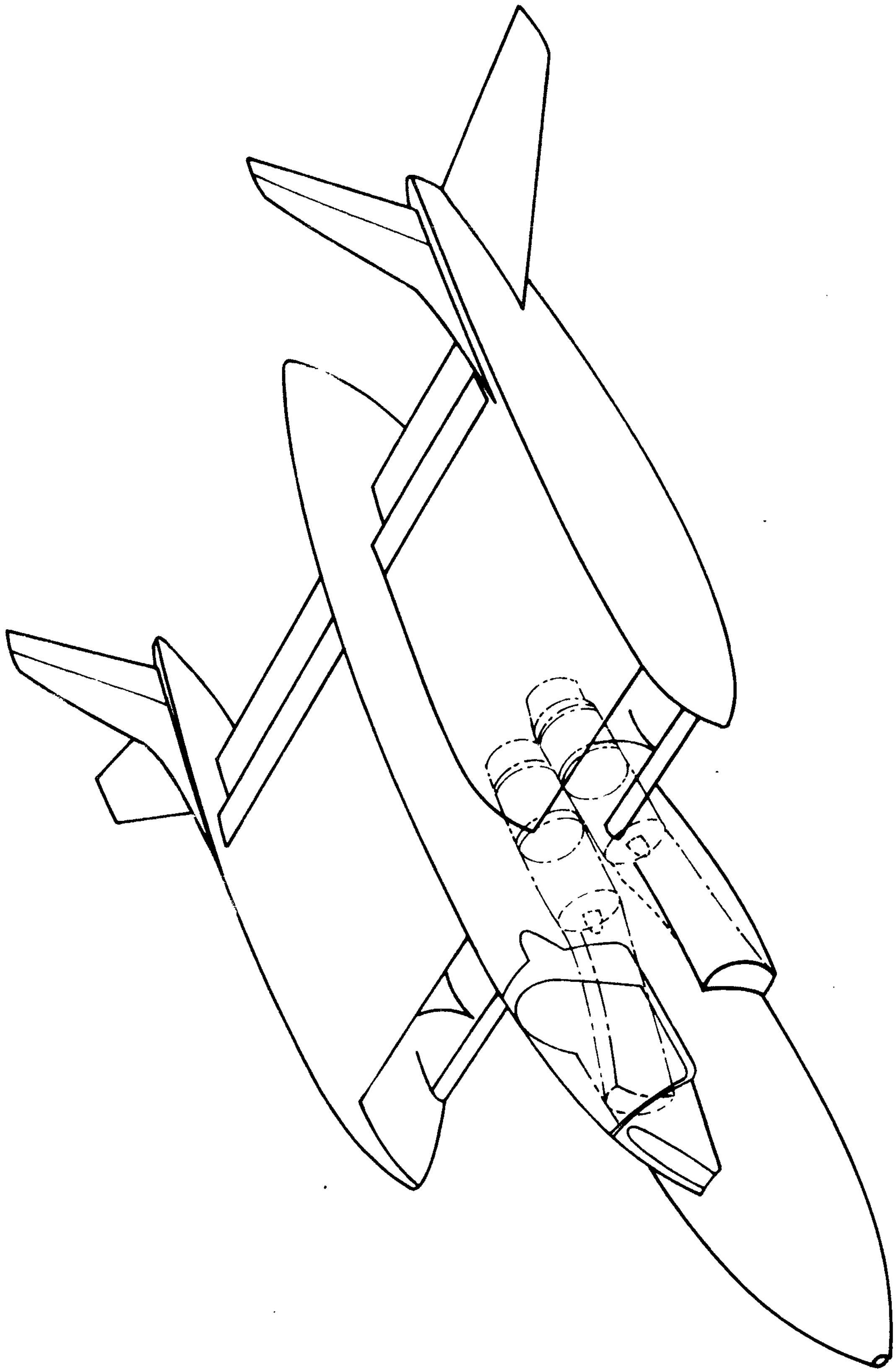

Figure H.2 Gas Generator Location and Inlet Configuration
Basic Configurations A.5, A.8, A.9, and A.10

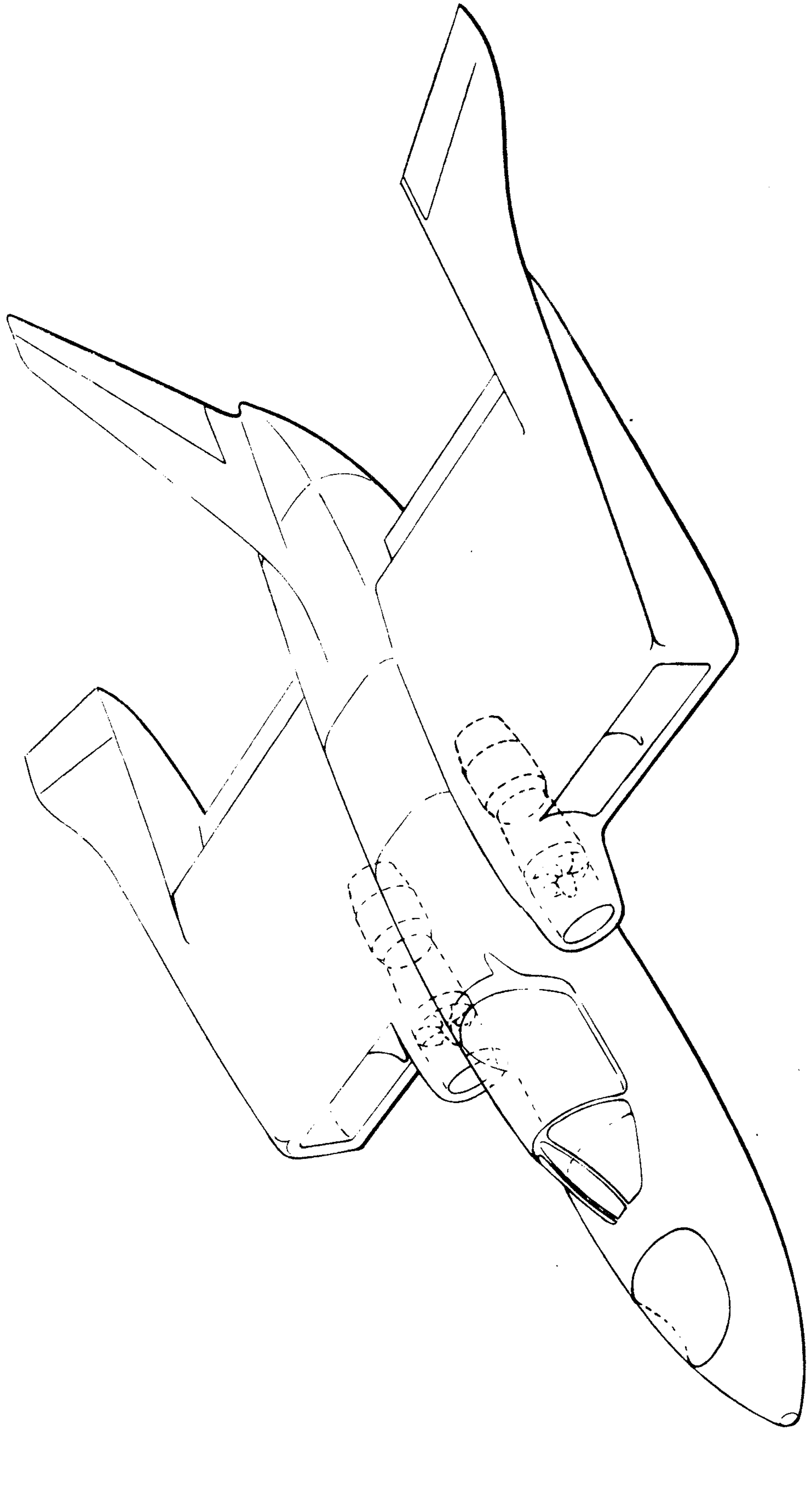

Figure H.3 Gas Generator Location and Inlet Configuration
Basic Configurations A.11 and Subsequent

I. HOT GAS DUCTING SYSTEM

In the ADAM I design shown in Figure I.1, the exhaust ducts from the two gas generators in each pod merged and then separated again before reaching the two power turbines. In this manner, either gas generator could drive both turbines. Check valves were needed to prevent reverse flows through an inoperative gas generator. A transverse duct interconnected the hot gas systems on the two sides of the airplane to provide for equalization with one gas generator inoperative. An actuated valve in the cross duct would be closed when engines were to be started. The two gas generators in one pod would have been started in unison.

The hot gas ducting for early ADAM II designs is shown in Figure I.2. One gas generator supplied hot gas to the two inboard power turbines; the other gas generator supplied hot has to the two outboard power turbines. Thus propulsion symmetry was maintained following an engine failure. Either gas generator could be started or shut down at any time, on the ground or in the air, without disturbing the other gas generator, and without using valves. Reasonably good cruise flight capability and runway landing capability were afforded with either gas generator inoperative or with either hot gas duct system destroyed.

On each side of the airplane, one power turbine rotated in one direction and the other power turbine rotated in the opposite direction. This served to cancel out gyroscopic couples, which could be troublesome in the hover mode.

The hot gas entered the power turbines through scrolls (volutes). This approach minimized the amount of turning that must be accomplished in the turbine first stage stator, or "nozzle diaphragm". It also eliminated any need for the shaft to pass through a hot gas zone in leaving the turbine. In the first ADAM II propulsive wing sections, the shafts for the inboard fans had to pass through the hot gas ducts leading to the outboard power turbines. With the advent of Wing Section B.2 and in all subsequent designs, the hot gas ducts were located above the fan shafts, eliminating any need having fan shafts pass through hot gas ducts. To accomplish this feature with Wing Section B.2, it was necessary to use elliptical ducting to pass the outboard hot gas ducts over the inboard fan shafts, at some considerable penalty in weight. By redesigning so that the major portion of the fan outlet flow passed under the power turbines, as in Wing Section B.3, or so that all of the fan outlet flow passed under the power turbines, as in Wing Section B.4, space was provided for using round ducts to supply the outboard turbines.

With the hot gas ducting system shown in Figure I.3 and in all subsequent designs, both fans on one side of the airplane rotated in one direction, both fans on the other side of the airplane rotated in the opposite direction. This approach falls slightly short of ideal if RPM is allowed to vary in obtaining hover roll control, but it leads to better packaging of the power turbines and their volutes into the space available.

When the tip-turbine nose fan was incorporated into the concept, the tip turbine was furnished hot gas from one gas generator over half of its perimeter and hot gas from the other gas generator over the other half of its perimeter, maintaining longitudinal propulsion symmetry as well as lateral propulsion symmetry in the event of a gas generator failure. This hot gas ducting is shown in Figure I.4. The two hot gas systems remained independent of each other, so that either gas generator could be started or shut down without disturbing the other gas generator, and without using valves.

Actuated shut-off valves were, of course required in the two ducts leading to the tip turbine nose fan to inactivate it for the cruise mode.

When the changeover to the forward-facing, continuously-running nose fan was made, the turbine driving the nose fan was located back in the same bay as all of the other hot gas components. This bay was aft of all wing primary structure. The nose fan was driven by a long shaft. This arrangement is depicted in Figure I.5. The exhaust from the nose fan turbine was discharged over the trailing edge flaps, half on each side of the fuselage, along with the exhaust from the wing fan power turbines. This design achieved the ultimate in minimizing the possibility of encountering hot gas reingestion, because all hot gas was exhausted into a zone remotely located from all inlets and shielded from the inlets by the high mass rate curtain of cold fan discharge air.

With reversion to a tip-turbine nose fan as shown in Basic Configuration A.12, the hot gas duct system became as shown in Figure I.6. Since the close support mission included a considerable content of loiter and low powered cruise, it was found advantageous to fly with one gas generator at flight idle and the other at the power setting consistent with furnishing the total thrust required. Therefore, a hot gas ducting design was selected in which each gas generator furnished hot gas to half the periphery of each power turbine. Thus in cruise all wing fans were powered equally whether or not both gas generators were at equal power settings or even both in operation. This approach affords the best possible one-engine-out cruise. The two hot gas systems remain independent. Each furnishes hot gas to part of the periphery of the nose fan tip-turbine. It is planned through partial admission to supply hot gas only to the forward half of this tip-turbine so as to minimize the possibility of encountering hot gas reingestion. The hot gas for the nose fan leaves the gas generators and enters the nose fan ducts without change in direction of flow, preserving the velocity head. It is turned to the forward direction through long sweep 180 degree bends. Valves are provided for shutting off the hot gas flows to the nose fan during the cruise mode, introducing one small additional item to pilot work load.

The tip-turbine nose fan gains some advantage from the fact that its component of hover thrust due to the hot gas jet (approximately 15%) is exerted at the extreme front end of the airplane instead of behind the trailing edge flaps.

The hot gas ducting system for General Arrangement A.13 is essentially the same as for A.12.

Various other approaches have been studied, particularly the one in which the flows from all gas generators are manifolded into one plenum. This arrangement, often proposed for transports, has been avoided when possible because all gas generators have to be trimmed down to the level of the weakest gas generator in order to safeguard against stalling it. Complex valving and waste gate arrangements are needed to permit restarting gas generators. And finally, major damage to the common hot gas duct system would cripple the entire propulsion system unless elaborate valving arrangements were devised to provide segregation of damaged portions of the common duct system.

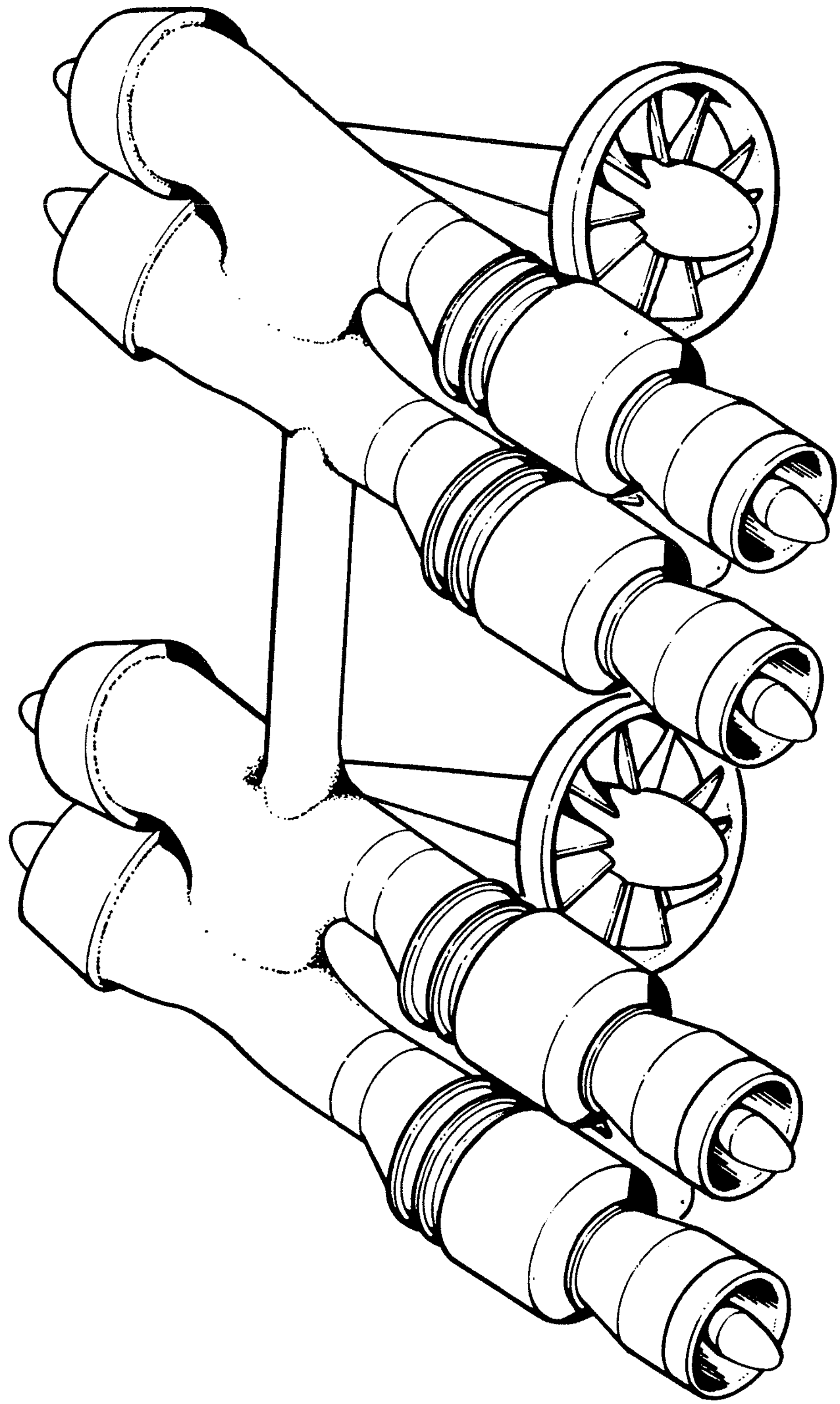

Figure I.1 Hot Gas Ducting System All ADAM I Basic Configurations

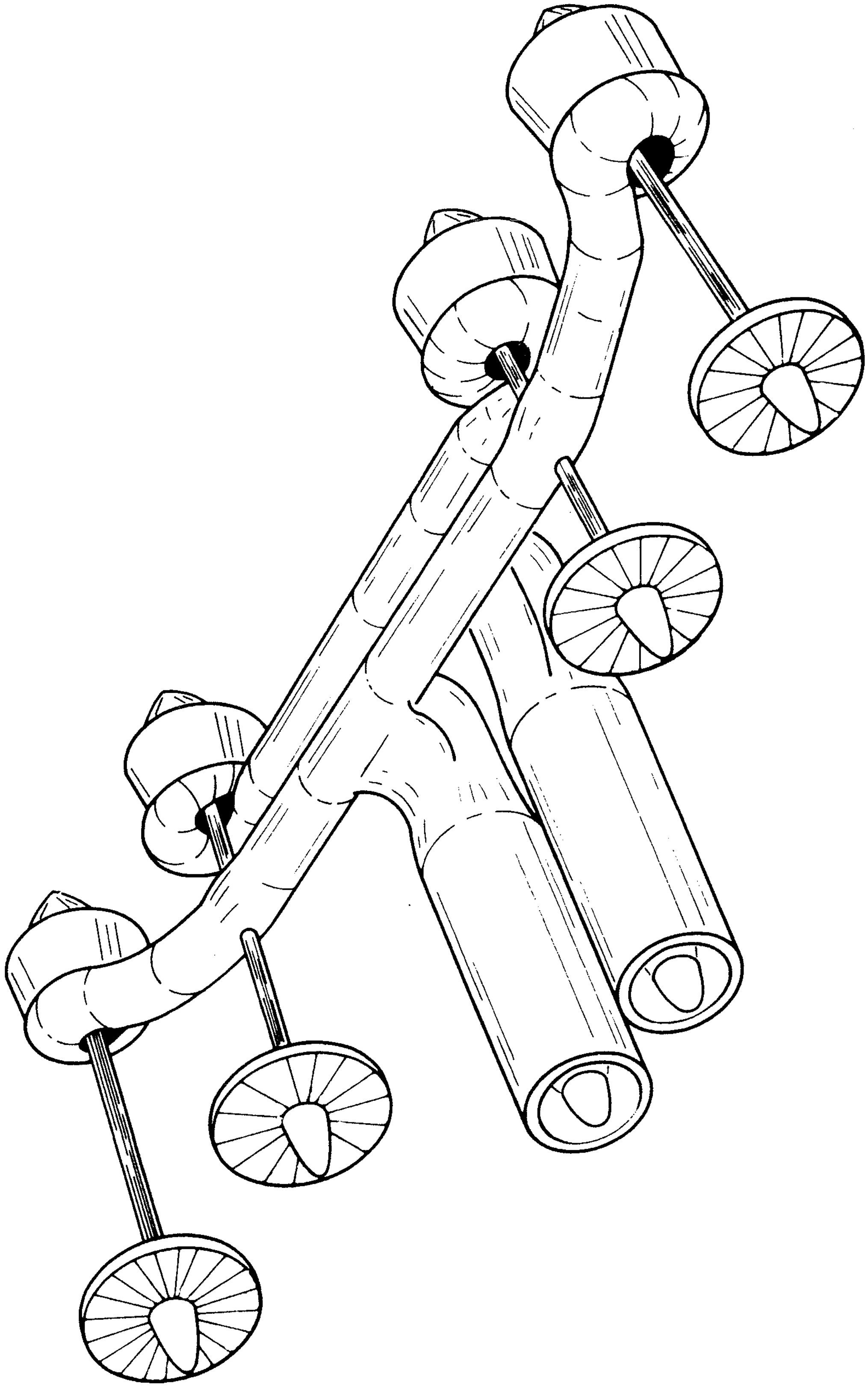

Figure I.2 Hot Gas Ducting System Basic Configuration A.4

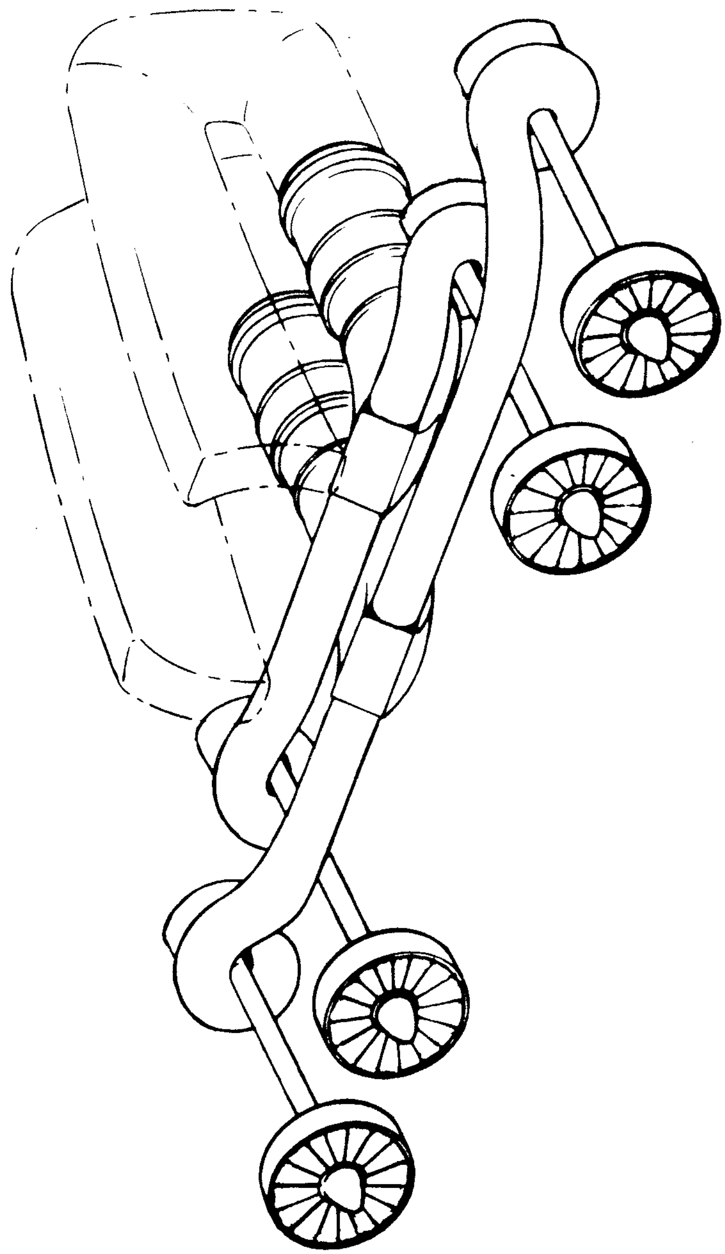

Figure I.3 Hot Gas Ducting System Basic Configuration A.6

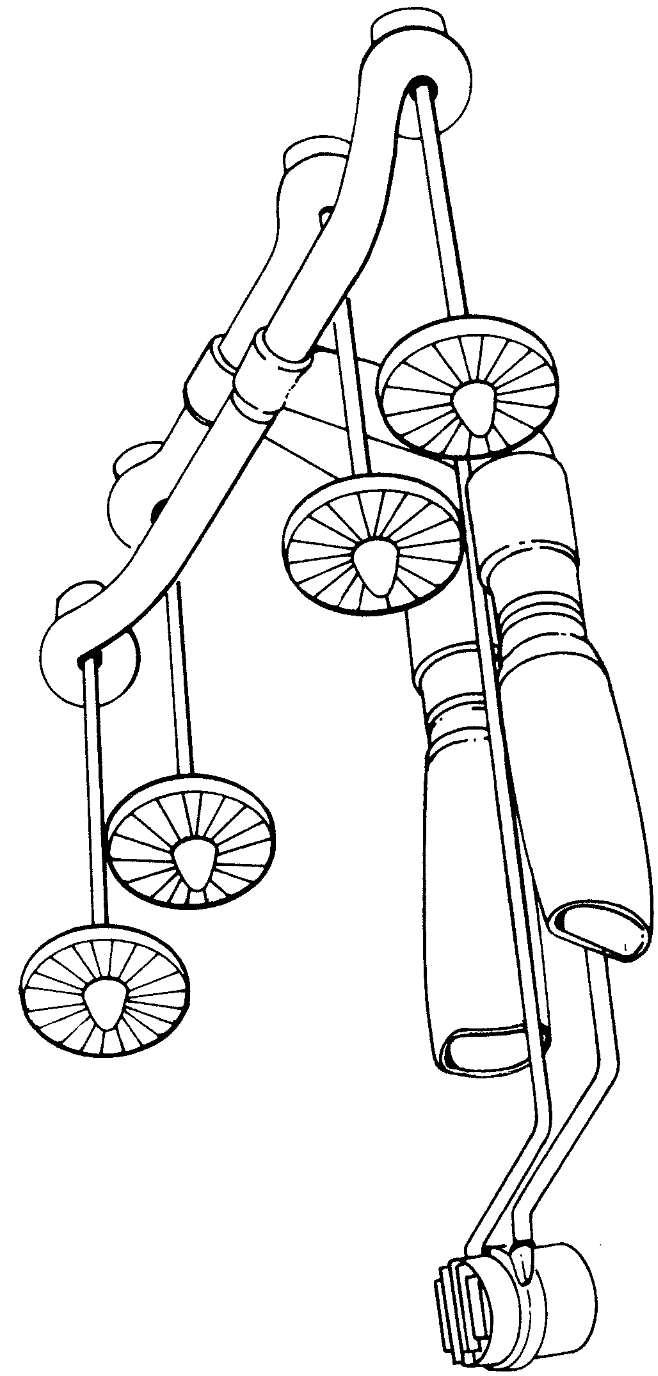

Figure I.4 Hot Gas Duct System Basic Configurations A.8

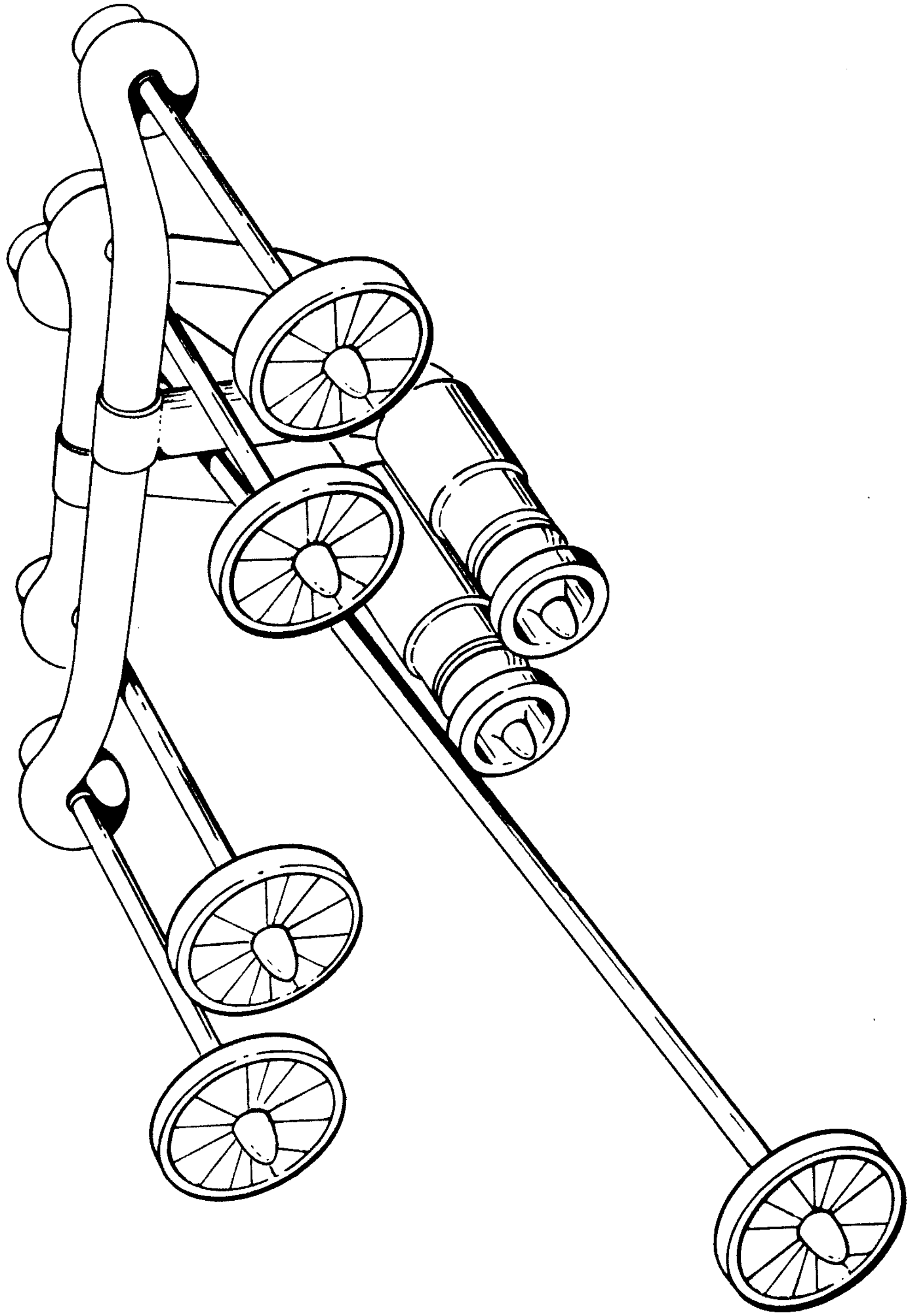

Figure I.5 Hot Gas Ducting System Basic Configuration A.9, A.10, and A.11

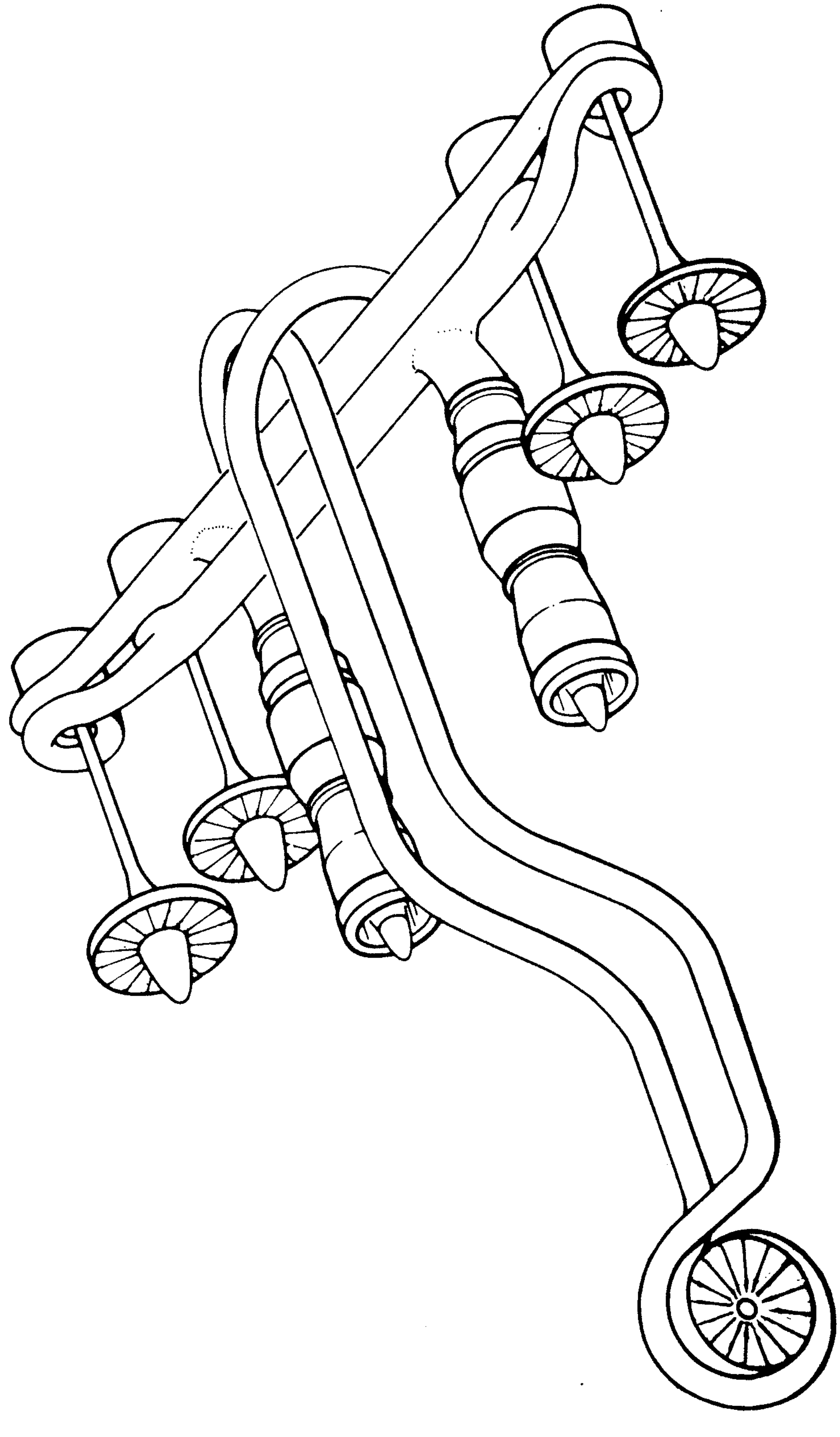

Figure I.6 Hot Gas Ducting System Basic Configuration A.12

J. LANDING GEAR

In the ADAM I designs the main landing gear was generally mounted in the fuselage, as shown in Figure J-1. With the rearward Center of Gravity location of this design, the main gear was behind the fan jet during full hover, but it was exposed to the fan jet during part of the transition. A kneeling nose gear was contemplated to provide a level attitude for loading and a nose high attitude for STOL take-off.

With the advent of the outboard tail with its tail booms, the main gear was at first mounted in the booms. In the earlier designs with a rearward Center of Gravity location, the main gear was generally retracted forward as shown in Figure J.2.

With the advent of more powerful engines, it became possible to balance the airplane without resorting to reverse flow through the gas generators. This opened up room in the fuselage for a bicycle type of landing gear as shown in Figure J.3. Long stroke, light load outriggers were mounted in the booms for lateral balancing. The outrigger wheels were castered to minimize side loads. The main landing gear was at the normal fore and aft location, instead of being much farther aft as is the case for the B-17 and B-52 bicycle gears.

More careful structural design studies indicated that the loads introduced by having the main landing gear in the booms would not exceed flight loads in an attack airplane, and the main gear was moved back to the booms in the design shown in Figure J.4.

When the engines were moved to the wing roots in a late 1967 design and the wing span was increased accordingly, it was found that to locate the main gear in the booms would produce too wide a tread. Previous experience with overly wide treads in other airplanes had shown excessive sensivity to minor differences in braking action, one side versus the other. On the other hand, a conventional fuselage mounted gear which kept out of the fan jets would provide too narrow a tread for a V/STOL airplane. Therefore, it was decided to revert to the bicycle type of gear which had been studied previously. With the gas generators and their inlets removed from the fuselage, ample volume was made available to house the main gear along with avionics, internal fuel, etc. in the fuselage

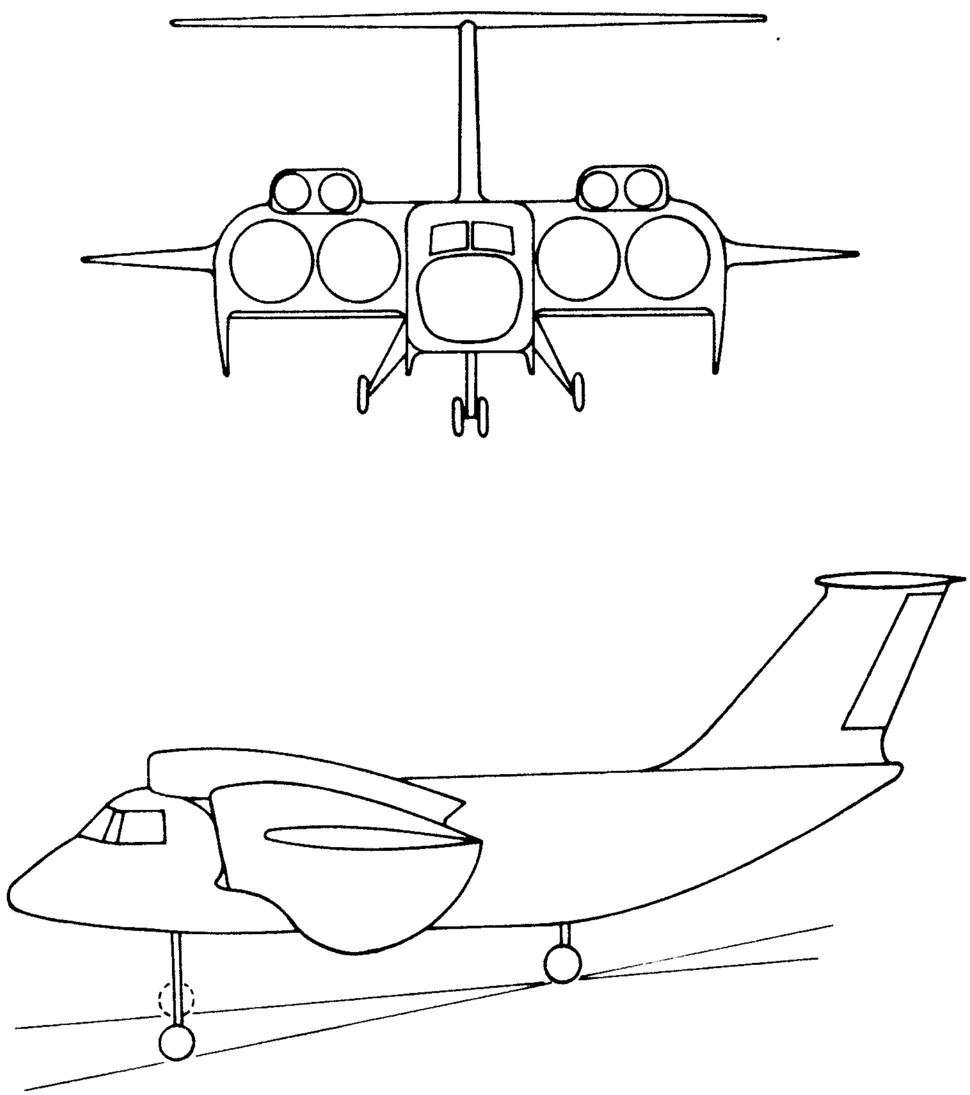

Figure J.1 Landing Gear ADAM I Configurations

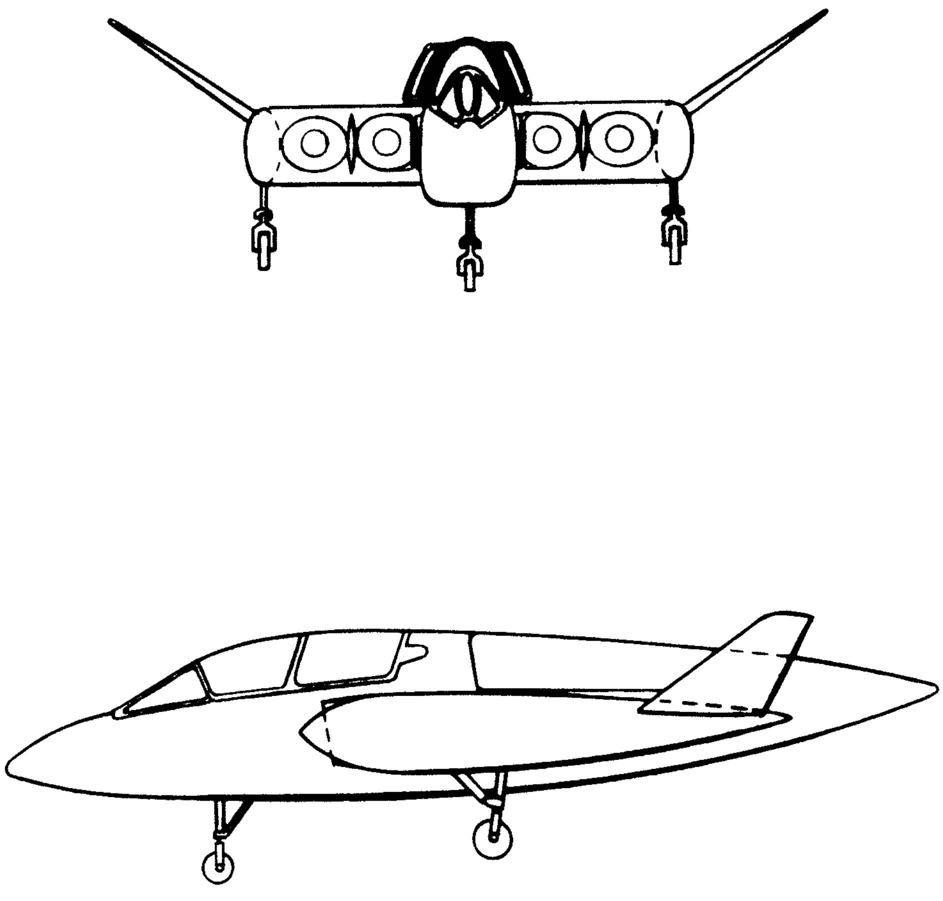

Figure J.2 Landing Gear Basic Configurations A.4, A.5, and A.6

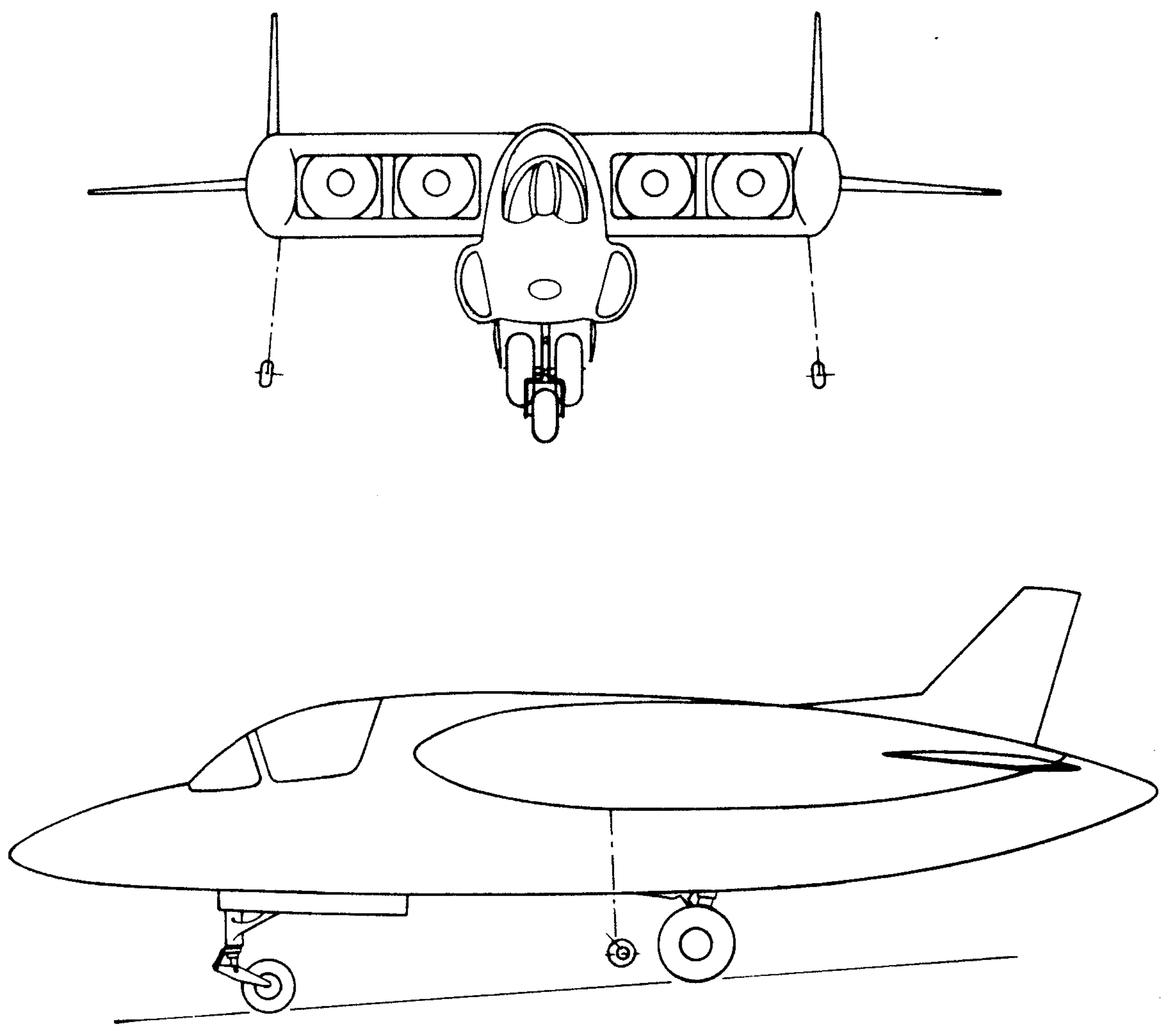

Figure J.3 Landing Gear Basic Configuration A.8

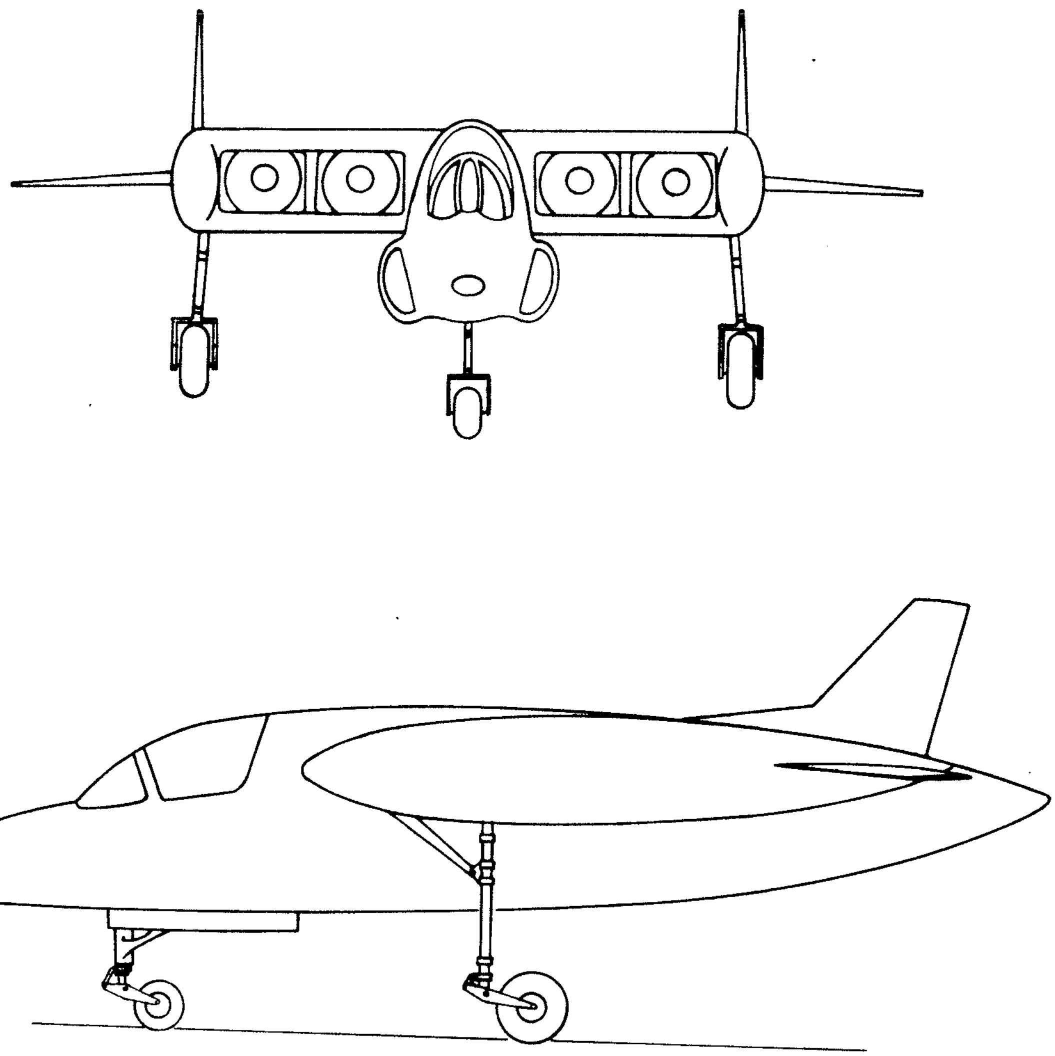

Figure J.4 Landing Gear Basic Configuration A.9

K. ADAM PUBLICATIONS

1. "ADAM II Advanced Turbofan V/STOL Test Program - Combined High and Low Speed Wind Tunnel Tests of Fan Powered Model (U)," LTV Report No. 2-55400/5R-2199, 30 April 1965.

2. "The Propulsive Wing Turbofan V/STOL," B. R. Winborn, Jr., SAE National Aeronautic Meeting, 12-15 April 1965, Paper No. 650 203.

3. "V-460-A ADAM II V/STOL Transport," LTV Report No. 2-55400/5R-2177, 12 February 1965.

4. "V-468 ADAM II Recce/Strike V/STOL Airplane," LTV Report No. 2-55400/5R-2176, 12 February 1965.

5. "Weight Analysis of Adam Propulsive Wing Turbofan V/STOL Airplane," LTV Vought Aeronautics Division paper presented at the Twnety-fifth Annual National Conference of the Society of Aeronautical Weight Engineers, 2 May through 5 May 1966.

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7. "Planning Document, ADAM II Experimental Program," LTV Vought Aeronautics Division Report 2-55400/6R-50331, 17 January 1966.

8. "Planning Document - ADAM II Experimental Program," LTV Report No. 2-55400/6R-50331, Revised 30 June 1967.

9. "ADAM II Propulsion System and Internal Aerodynamics," C. T. Havey, Paper 670353, SAE National Aeronautics Meeting, New York, N. Y., April 24-27, 1967.

10. "ADAM II Propulsion System and Internal Aerodynamics," C. T. Havey, SAE National Aeronautics Meeting, New York, N. Y., April 24-27, 1967, SAE Paper No. 670353.

11. "A-X ADAM II Fan Powered V/STOL Concept (U)," VAD CONFIDENTIAL Report No. 2-55400/7R-50438, December 1967.

12. " V/STOL Close Support Capability - ADAM III (U)," VAD CONFIDENTIAL Report No. 2-55400/8R-50474, June 1968.

13. " Survivibility Analysis, ADAM III vs. .50 cal Quad Mount (U)," D. M. Reedy, VAD CONFIDENTIAL Letter 2-55100/8M-1250, 13 June 1968.

14. "The Evolution of the ADAM Concept, B. R. Winborn, Jr., VAD Report No. 2-55400/8AVO-T-101, 11 July 1968.

15. "Recent Results in the Development of the ADAM II Propulsive Wing V/STOL Concept," J. K. Davidson, AIAA 5th Annual Meeting & Technical Display, Philadelphia, Pa., October 21-25, 1968

APPENDIX A

ADAM CONCEPT PHILOSOPHY

1. Align the Inlets with the Flow.

   a. Strong cross-flows are sure to be troublesome

2. Propel the Flow with minimum Weight Components

   a. Direct-drive turbo-machinery

3. Select Modern, Light-weight Turbo-Gas Generators.

   a. J60, J85, T58. J52

4. Install enough Gas Generator Power to yield a compact, fast Aircraft.

5. Interconnect the Hot Gas Flows in order to attain Engine-out Equalization.

6. Provide a Positive Means for controlling the Hot Gas Flow through the Equalization Cross-duct.

   a. Thereby assuring positive lateral trim with one engine inoperative.

7. Shroud the Fan with Ducting

   a. To afford positive vectoring of the fan flow.

   b. To minimize the required Fan Tip Diameter.

8. Place Two Fans Side-by-Side in each Propulsion Unit

   a. To provide a high aspect ratio duct for more efficient flow vectoring.

   b. To provide a preferred external shape (See 15 below).

9. Deflect the Flow downward efficiently for Vertical Thrust.

   a. By moving the walls of the high aspect ratio duct.

10. Design for enough maximum Thrust Vector Deflection to afford an adequate Reverse Thrust Component during the Landing Approach without Rotation of the Aircraft to a Stalling Attitude.

11. Obtain Reaction-Mode Longitudinal Balance and Control by means of Translation of the Fan Jets.

    a. With no sacrifice of lifting potential

12. Obtain Reaction-Mode Directional Balance and Control by means of Differential Vectoring of the Fan Jets.

    a. With only negligible sacrifice of lifting potential

13. Obtain Reaction-Mode Lateral Control through use of Differential Variation of Area of Right and Left Fan Nozzles in Each Propulsion Unit.

    a. With minimum sacrifice of lifting potential

    b. Obtain sustained Lateral Moments by means of Directed Hot Gas Cross-flow (See 6 above)

14. Direct the Fan Flow rearward for Forward Flight.

    a. By moving the walls of the fan duct.

    b. Capitalizing upon the good propulsive efficiency obtainable with the fan flow

15. Configure the External Shape of the Twin-Fan Propulsion Unit so that it provides Good Aerodynamic Lift at Minimum Profile Drag during Normal Forward Flight.

16. Use the strong fan flows to induce the desired external flows.

17. Optimize the Fan Pressure Ratio so as to provide the Best Balance between Lift-off Capability and High Speed Capability in accordance with Mission Requirements.

a. Compromising fan design if necessary in order to improve turbine design.

October 1958

APPENDIX B

ADAM TESTS CONDUCTED TO DATE

The tests on the ADAM concept that have been conducted to date are summarized below in outline form:

1. ADAM I Low Speed Wind Tunnel Test

Model: 0.15 Scale model of an ADAM I light transport, ram-powered, interchangeable tail surfaces.

Facility: LTV Low Speed Wind Tunnel

Test Dates: 14-26 October 1959 and 7-11 December 1959

Report: J. P. Young, "Low Speed Wind Tunnel Tests of a 0.15 Scale Model 'ADAM' VTOL Airplane Series I and II," Report AER-EOR-12775, dtd 8 Mar 1960. Proprietary.

Key Results:

(a) Good Lift

(b) Local stalls, which were eliminated by re-configuration in ADAM II.

(c) Encouraging results from crude outboard tail configuration, tested after centerline tail configurations exhibited low $\left(1 - \frac{d\epsilon}{d\alpha}\right)$ values.

2. ADAM I Propulsive Duct Flow Test

Model: 0.25 Scale model of twin fan propulsive duct

Facility: Large plenum chamber using compressed air from LTV High Speed Wind Tunnel Air Supply

Test Date: 1 Oct - 31 Oct 1959

Report: W. E. Rice and K. D. Holliman, "ADAM-VTOL: Flow Tests of a .25 Scale Model of the Propulsive Duct," Report EOR-12603 dtd 15 January 1960. Proprietary.

Key Results:

(a) Low vectoring losses.

3. Potential Flow Tests of ADAM II Ducted Fan and Equivalent Collapsed Solid Body

Model: (a) Representation of ADAM II ducted fan with Quermann inlet.

(b) Equivalent collapsed solid body.

Facility: LTV Research Center Rheoelectric Analog Potential Flow Facility.

Test Date: 1963

Report: J. K. Davidson, "Pressure Coefficients on the ADAM II Shroud and the Ruden Inlet Diffuser from Tests on the Rheoelectric Analog Facility," Memo 0-71000/3A-485 dtd 11 Sept 1963, Proprietary.

Key Results:

(a) Substantial differences in pressure coefficient and velocity coefficient profiles over the two models, but enough similarity for a first approximation of effective thickness of ADAM II propulsive wing.

4. ADAM II High Speed Wind Tunnel Test

Model: 0.03 Scale model of an ADAM II light transport, ram-powered, interchangeable fan inlets and nozzle plugs.

Facility: LTV High Speed Wind Tunnel

Test Dates: 4-8 Sept 1963

Report: F. L. Beissner, "Results of Initial High Speed Wind Tunnel Test on ADAM II," Report 2-53310/4R-50173, dtd 7 Feb 1964. Proprietary.

Key Results:

(a) Flight through Mach 0.9 with very little drag divergence.

(b) Confirmation of outboard tail concept, with

$$1 - \left(\frac{d\epsilon}{d\alpha}\right) = 1.5$$

(c) Good inlet performance at high speeds.

5. ADAM II Low Speed Wind Tunnel Test of Semi-Span Model, funded by Army Research Office, Durham, N. C.

Contract: DA-31-124-ARO-D-262

Model: 0.19 Scale semi-span model of recce/strike airplane with simplified fuselage, faired over inlets, with compressed air brought aboard to simulate fan and turbine outlet flows. Interchangeable cascade boxes, adjustable flap and outboard horizontal tail.

Test Dates: 25 October - 13 November 1964

Report: R. T. Stancil and L. J. Mertaugh, jr., "Analysis of Low Speed Wind Tunnel Model of a High Mass Rate Vectored Propulsion Flow Model," Report 2-53310/4R-2166, dtd 15 February 1965.

Key Results:

(a) Excellent performance of outboard tails.

(b) Suckdown forces small.

(c) Good jet flap effect with trailing edge flap.

Contract: DA-31-124-ARO-D-262-Mod. 3

Model: Same

Report: L. J. Mertaugh, Jr. and J. K. Davidson, "Analysis of a Follow-On Low Speed Wind Tunnel Test of a High Mass Rate Vectored Propulsion Flow Model", Report 2-53310/5R-2206, dtd 31 Jul 1965.

Key Results:

(a) Ground effect was investigated, showing some loss in static thrust close to the ground.

(b) Flow fields around the outboard tail were investigated.

6. ADAM II Hi/Lo Model Wind Tunnel Tests

Model: 0.167 Scale model of an ADAM II strike/recce airplane powered by four wing fans and one nose fan.

Contract: AF33(615)-3293 funded jointly by the U. S. Air Force and the U. S. Army.

A. Shakedown Test in LTV 7 ft x 10 ft Low Speed Wind Tunnel.

Test Dates: 2 December 1966 - 7 December 1966 - 7 December 1967

Report: R. D. Meyer, J. J. Kendro and R. B. English, "Design, Fabrication, Testing and Data Analysis of ADAM II Concept (Propulsive Wing). Part II, Shakedown Testing in LTV 7 ft by 10 ft Low Speed Wind Tunnel, dtd May 1968.

Key Results:

(1) Unsatisfactory performance of outboard (boom-mounted) vertical tails.

(2) Good performance of outboard horizontal tails with 60° sweep leading edges.

B. Sub-transition Testing at NASA Langley Research Center.

Test Dates: 5 January - 31 January 1967.

Report: R. D. Meyer, W. E. Brownrigg, R. B. English, et al, "Design, Fabrication, Testing and Data Analysis of ADAM II Concept, (Propulsive Wing), Part III, Testing in the Langley Research Center 17 ft Test Section, dtd May 1968.

Key Results:

(1) Good directional stability with vertical tail mounted on aft section of the fuselage.

(2) Positive dihedral effect, good lateral-directional characteristics.

(3) Small ground effects.

(4) Non-linear pitching moment curves with fan flow deflected 30°.

C. Cruise and High Speed Testing at NASA Langley Research Center.

Test Dates: 2 June 1967 - 7 July 1967.

Report: "Design, Fabrication, Testing and Data Analysis of ADAM II Concept (Propulsive Wing), Part IV, Testing in Langley Research Center 16 ft Transonic Wind Tunnel, dtd May 1968.

Key Results:

(1) 0.9 Mach Number for force divergence.

(2) Good longitudinal stability characteristics, forty to fifty percent larger horizontal tails needed.

(3) Good lateral-directional characteristics, thirty percent larger vertical tail volume needed.

(4) Excellent lift characteristics.

(5) Drag measurements are suspect due to:

   (a) Uncertainties associated with sting interference.

   (b) Uncertainties associated with sting cavity correction.

   (c) Excessive model leakage.

   (d) Fan inlet spillage and additive drag due to limitations in fan capabilities.

(6) Airplane performance based on test drags is competitive.

(7) Improvement expected after corrective action is taken.

7. Static Tests of ADAM II Twin-Fan inlets

Model: Twin fan inlets for $6\frac{1}{2}$" diameter fans, adapter from inlets to test duct dummy fuselage and boom.

Contract: NAS2-3714 (NASA Ames Research Center, funded by the Army Aeronautical Research Laboratory at Ames)

Facility: LTV Engine Test Cell Nr. 4, powered by J33-A20 jet engine loaned by the U. S. Navy.

Test Dates: 22 December 1966 - 27 January 1967.

Report: J. R. Colburn IV, C. N. Webster, and C. T. Havey, "ADAM II Static Inlet Test Report" VAD Report No. 2-53910/7R-50422, dtd 25 September 1967.

Key Results:

(1) High recovery with good distribution obtained with Length/Diameter = 1.0 inlet.

(2) Extensive data obtained on effects of duct length, inlet radius, and transition strips.

APPENDIX C

ADAM TESTS NOW IN PROCESS

The tests on the ADAM concept that are now in process are summarized below in outline form:

1. Investigation of the Effects of Fan-generated Turbulence on the Flow in Ducts, Bends and Diffusers.

   Contract: NAS2-3714(NASA Ames Research Center, funded by the Army Aeronautical Research Laboratory at Ames).

   Facility: Bench Test Using LTV Low Speed Wind Tunnel Air Supply.

   Test Dates: 9 January 1967 - 16 February 1967, 27-29 May 1968

   Key Results:

   (1) Low vectoring losses in open bend, with good distribution at face of the fan attained by "ADAM's Apple" contouring.

2. Internal Aerodynamic Test of ADAM II Concept

   Contract: NAS2-3714 (NASA Ames Research Center, funded by the Army Aeronautical Research Laboratory at Ames)

   Model: 0.190 scale semi-span model of an ADAM II strike/recce airplane powered by two $6\frac{1}{2}$ inch diameter shaft-driven wing fans, with release of compressed air to simulate nose fan efflux. This model was obtained by modifying the semi-span model procured by ARO-Durham under contract No. DA-31-124-ARO-D-262.

   Facility: Army Aeronautical Research Laboratory at Ames, 7 ft x 10 ft Low Speed Wind Tunnel.

   Test Dates: Mid-1968.

APPENDIX D

ADAM DESIGN STUDIES

1. USAF SR-175

This was an unpaid study conducted under ground rules promulgated in USAF SR-175.

Work was concentrated on a 25,000 lb gross weight ADAM I transport. It was powered by four Pratt & Whitney Aircraft JT-12 engines. Full engine-out safety was provided. The summary report was submitted in February 1960.

2. USA ASR 3-60

This was an unpaid study conducted under ground rules promulgated in U. S. Army ASR 3-60. Work centered around a 35,000 lb gross weight transport powered by four Pratt & Whitney Aircraft JT-12 engines. This airplane did not have full engine-out safety, but retained most of its lifting capability with one engine out. A decision in favor of outboard horizontal tails had been made by the time this transport was designed. The report was submitted in January 1960.

3. LTV V-460 TRANSPORT

This was a company-funded study of an early ADAM II V/STOL transport in the eight-ton payload category. It was powered by five Pratt & Whitney Aircraft J52 gas generators. Its performance was compared by LTV to that of competitive designs for other concepts. Particulars on the V-460 are given in LTV Report 2-55400/3R-185-1A dtd 15 September 1963. This design was evaluated one and one-half years later by an Air Force evaluation team at Wright-Patterson Air Force Base and compared to direct lift engine designs. The team concluded that the ADAM concept should be fully evaluated in connection with the CX-6 program.

4. COMPARATIVE EVALUTION

At the Air Force's suggestion, a comparative evaluation was made of the ADAM II concept and the Fan-in-Wing concept as follows. Preliminary design studies were conducted for surveillance airplanes of the two concepts, each powered by two uprated J85 engines. The LTV design for the Fan-in-Wing airplane incorporated some improvements which have been adopted in succeeding Fan-in-Wing designs made by other companies. By the same token, detailed work on the Fan-in-Wing airplane revealed to LTV unexpected advantages accruing from the use of the nose fan. Nose fans have been incorporated in succeeding ADAM II designs. The report, entitled "Comparative Evaluation of the Fan-in-Wing and ADAM II V/STOL Surveillance Airplane," was issued in January 1964. ADAM II airplanes were found to be lighter, with the advantage increasing as radius of action was increased.

5. LTV V-468 RECCE/STRIKE AIRPLANE

This was a company-funded study of a single seat, high wing, recce/strike airplane powered by two GE/J1 gas generators. This engine was the first one studied in the ADAM program that was really well-suited for the purpose. By now, equally suitable Pratt & Whitney and Allison engine designs have been reported upon. The V-468 performance calculations reflected the unexpectedly favorable results of an LTV high speed wind tunnel test and of a low speed wind tunnel test sponsored by the Army Research Office - Durham. Information on this design was released in LTV Report 2-55400/5R-2176 dated 12 February 1965.

6. WING AND BOOM STRUCTURE STUDY

A preliminary study was made of the structural arrangement of the wing, main landing gear, tail boom, and empennage of an ADAM II airplane. Load paths and methods of assembly were determined. The results were published in VAD Report No. R12-118, "ADAM II Structural Arrangement," J. W. Patton, 25 October 1966.

7. SHORT-HAUL TRANSPORT STUDIES

Studies of short-haul VTOL and STOL commercial transports were made under Contract No. NAS2-3036 for the NASA Ames Research Center. Tilt-wing Turboprop, Fan-in-wing, and ADAM II types were investigated. The results were published in Report No. CR-670, "Study on Feasibility of V/STOL Concepts for Short-Haul Transport Aircraft," Keith R. Marsh, January 1967, and Report No. CR-670(01), "Additional Studies on Feasibility of V/STOL Concepts for Short-Haul Transport Aircraft," Keith R. Marsh, December 1967. The ADAM II concept transports were found to be fully competitive, although the cruise speeds stipulated were slower than would normally be used with ADAM II airplanes.

8. LIT STUDIES

A study of light intratheater transports of various concepts was made for the Air Force under Contract No. F33675-67-C-0701. The results were published in Report No. 2-55400/7R-6128, "Light Intratheater Transport Study Final Report," 21 July 1967. The ADAM II concept was found to be interesting for a time period further out in the future than that stipulated for this particular application.

9. CLOSE AIR SUPPORT STUDIES

Company-funded studies were made of ADAM II concept airplanes for close air support missions. The design in the first study had six wing fans, and the somewhat smaller design in the second study had four wing fans. The results were published in VAD Confidential Report 2-55400/7R-50438, "Close Air Support – ADAM II Fan Powered V/STOL Concept (u)," February 1968, and VAD Confidential Report 2-55400/8R-50474, "V/STOL Close Support Capability – ADAM II Four Fan Version (u)," June 1968. Presentations on the results were given to the various user activities.

10. SURVIVABILITY STUDIES

A preliminary vulnerability analysis of an ADAM III attack airplane to a .50 caliber API threat was conducted. The results were presented in "Survivability Analysis, ADAM III vs. .50 Caliber Quad Mount (U)." D. M. Reedy, VAD Confidential Letter 2-55100/8M-1250, dated 13 June 1968. Conclusions were highly favorable.

APPENDIX E

GAS POWER EXCHANGE HOVER CONTROL

After reviewing and analyzing many types of hover control systems, the ADAM project has grown to rely strongly upon a Gas Power Exchange or Power Transfer System which has been promoted by the General Electric Company. This system is illustrated in Figure AE.1.

The principle involved in the gas power exchange system is as follows. One gas generator furnishes hot compressed gas to more than one power turbines. By varying the inlet geometry of the two power turbines differentially, opening one while closing down the other with no change in total turbine nozzle diaphragm (first stage stator) area, more hot gas will be taken by one turbine than the other. The turbine taking more hot gas will develop more shaft horsepwoer, and the fan it drives can exert more thrust. The other fan exerts less thrust. Thus there is a transfer of thrust from one location in the airplane to another, with very little change in total thrust exerted.

Obtaining more thrust by expending more power involves one of the three following approaches:

1. Constant Fan Geometry

The fan delivered more power accelerates and balances out at a higher RPM at which it exerts more thrust. The time constant for this acceleration must be very small ($<$ 0.2 sec) or an alert pilot will overcontrol and set up a pilot induced oscillation. As the technology of turbo-machinery advances over the years, the components become lighter and more highly powered, and this approach becomes more attractive. With present technology, it is probably marginally acceptable. Some improvement may be obtained by employing a technique known as jazzing, in which a small change in control setting leads initially to a full change in power turbine geometry, which is then rapidly "washed out" as the turbomachinery responds.

2. Constant Fan RPM

In this approach, fan and turbine RPM are held constant, so that responses can be very rapid. When more thrust must be developed by expending more power, some change is made in fan geometry. The possible variations in geometry are.

a. Variable Jet Nozzle Area

This approach is readily adaptable to the ADAM concept and is most attractive within the limits of its effectiveness.

b. Variable Inlet Guide Vanes

Feasible and effective over a somewhat limited range. Quite unattractive from the standpoint of mechanical complexity. In addition, inlet guide vanes aggravate noise problems and must be anti-iced, whereas rotor blades need not be anti-iced.

c. Variable Rotor Blades

This is a last resort due to the mechanical complexity of providing variable pitch in a high speed rotating component.

3. Composite Approach

The composite approach employs variable fan nozzle area and also permits fan shaft RPM to vary. This approach is favored over the other two.

Application of the Gas Power Exchange principle to hover pitch and roll control is discussed in Sections E and F respectively of this report.

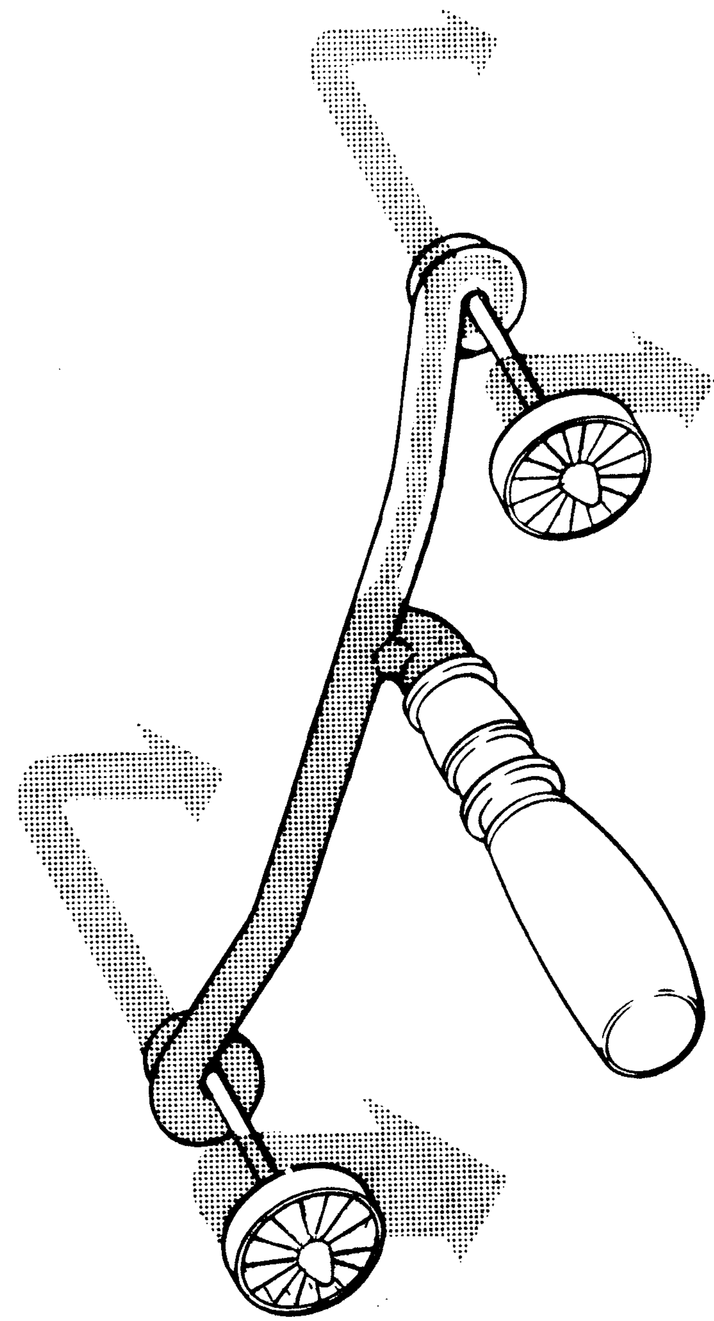

Figure AE.1 Gas Power Exchange Hover Control